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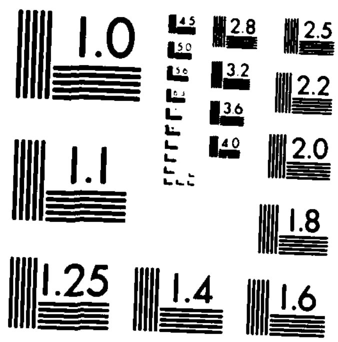

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FEASIBILITY OF MEASURING TECHNICAL PRODUCTIVITY IMPROVEMENTS IN AIR FORCE LOGISTICS COMMAND DEPOT-LEVEL MAINTENANCE USING THE DATA ENVELOPMENT ANALYSIS (DEA) AND CONSTRAINED FACET ANALYSIS (CFA) MODELS

THESIS

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THESIS

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Logistics Management

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Preface

Establishing the feasibility of using Data Envelopment and Constrained Facet Analysis Techniques for Air Force depot-maintenance productivity analysis applications is an important step forward. When Air Force Logistics Command implements a productivity analysis system that is academically valid and useful at all levels of management, an even bigger stride will have been taken. However, a system large enough to tie together an entire command's interests must begin with a series of small steps. Considerable research is still needed, not just with DEA and CFA applications, but with AFLC's productivity analysis needs.

In performing the research and writing the thesis, we wish to thank the following people. We are deeply indebted to Dennis Campbell and Lt Col Charles T. Clark, our thesis advisor and reader, for their immeasurable assistance in developing our research approach and writing this thesis. A special thanks goes to Barbara Pruett of HQ AFLC and Roger P. Dwyer of Sacramento Air Logistics Center for their part in leading us to an appropriate sample organization and in acquiring the necessary data.

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Abstract

In response to a Headquarters Air Force Logistics Command thesis proposal, this research demonstrated the feasibility of measuring technical productivity in a depot maintenance environment. Linear fractional programming techniques called Data Envelopment Analysis (DEA) and Constrained Facet Analysis (CFA) were used to show that the productivity of not-for-profit maintenance organizations can be reliably measured and directly supportive of management decison making. DEA/CFA analyses can measure multiple inputs and outputs simultaneously and display results in an easily understood format. This research stresses close cooperation between modelers and managers in selecting input/output variables so that information derived from the analysis can be used effectively. The results of this research were accepted by using managers as accurate, simple and useful in their decision making. Additionally, DEA/CFA techniques appear to have a wide range of potential uses in many Air Force organizations where productivity, capacity and resource allocation analyses are needed.

Feasibility of Measuring Technical Productivity Improvements in Air Force Logistics Command Depot-Level Maintenance using the Data Envelopment Analysis (DEA) and the Constrained Facet Analysis (CFA) Models.

I. Introduction

In today's world of rising costs and scarce resources, productivity has become one of the Air Force's most important priorities. Consequently, in the summer of 1983, senior maintenance managers at Headquarters Air Force Logistics Command (AFLC) formed a Productivity Measurement Working Group to develop a total factor productivity measure for depot-level maintenance. AFLC managers hoped a comparison of total productivity measurements would display the most efficient organizations and unearth some new enhancement techniques to increase productivity, reduce costs and increase production.

Statement of the Problem

Headquarters AFLC established a productivity enhancement program in 1980. Most AFLC productivity enhancement efforts have been in the areas of "Methods Improvement Programs" and "Quality of Working Life Programs." Overall, twenty-nine of those programs are listed in the 29 April 1983 AFLC Supplement to Air Force

Regulation (AFR) 25-3, Air Force Productivity Enhancement Program (PEP) (17:9-14). These programs represented considerable effort and, presumably, productivity improvement. However, the lack of effective productivity measurements made quantifying the productivity improvements speculative. Quantifying the results was important because productivity improvement efforts invariably required investment costs and measurements were needed to show acceptable return-on-investments (22).

The problem was stated in May 1983 by Joseph Gertge of Headquarters AFLC, Directorate of Maintenance, Financial Management and Productivity Analysis Division, in a proposed Air Force Institute of Technology (AFIT) thesis research topic as:

> All efforts to date, to measure materials, energy, and capital productivity in AFLC have been less than successful. A system of standards, data collection and a measurement formula must be designed to provide a total factor (labor, material, energy, capital) productivity index. Additionally, a separate measurement of productivity should be developed for each input, i.e. material, energy, capital, and labor [16].

The problem still must be resolved.

Objectives

The objectives of this thesis are to:

1. Define productivity for AFLC Depot-Level Maintenance.

2. Establish criteria to select input and output measurements for model simulation.

3. Develop the relationship between selected AFLC maintenance production inputs and outputs using the Data Envelopment Analysis (DEA) developed by Charnes, Cooper and Rhodes (6) and Constrained Facet Analysis (CFA) developed by Bessent, Bessent, Clark and Elam (5).

4. Evaluate the DEA and CFA models and show their advantages to other measurement techniques using data provided by Hq AFLC.

5. Suggest appropriate Air Force applications of the DEA and CFA models based on this research.

Scope

The development of increased productivity concerns is presented in a brief history of the productivity discipline, development of key definitions, and a description of the current Department of Defense and U.S. Air Force productivity programs. The reader should note that Appendix A contains a glossary that defines terms that are specific to this research. This thesis examines two specific measurement models: the DEA model and the CFA model. The DEA and CFA models evaluate the data provided by Hq AFLC. The results of the models' simulation are analyzed by the authors and examined by managers. However, the following assumptions are made:

1. Data provided by Hq AFLC is valid, accurate and based on empirical evidence.
2. The DEA and CFA models are theoretically valid as productivity measurement techniques. Support of this assumption can be found in research by Charnes, Cooper and Rhodes (6; 7) and Bessent, Bessent, and Clark (4) and Clark (8).

II. Literature Review

Background

In the 20th century, productivity has gained importance from a discussion topic to a true field of inquiry. Many of America's best economic minds devote considerable time to analyzing ways to improve productivity because of the motivation of expected benefits from such improvements. Firms know the benefits derived from improving productivity in the long run add up to continued existence of the firm. Much is made in today's media of the differences in productivity between American industry and industries in countries such as Japan and West Germany.

This preoccupation with productivity is mirrored in the military community. The Department of Defense (DOD) has a productivity program and dictates that each major function of the department have one also. Why?

The answer may be found by looking at incentives. The not-for-profit organization, such as DOD, is of value to society as long as its products or services can be provided at an acceptable cost (economic or noneconomic). When this situation prevails, the organization is generally thought of as productive.

Before World War II productivity measures were *primarily* focused on labor efficiency. It was not until 1942 that the first empirical measure of total productivity

was attempted. The concept of Total Factor Productivity (TFP) was first advanced in popularity in economic circles by John Kendrick at a 1951 National Income and Wealth Conference (18:3). According to Kendrick, the expansion of productivity measurement, because of growing recognition of its importance, has resulted in a distinct new field of inquiry. TFP and intense theoretical thought on the subject have parallel developments, both beginning about 1950 (18:3-4).

Americans pioneered development of the productivity field but the U.S. as a nation was slower than other nations to capitalize on the potential advancements. Japan, because of rapid national rebuilding and with the encouragement of U.S. foreign aid, used productivity measurements to keep its postwar reconstruction efforts on track from the beginning. This can be seen in the development of national productivity centers (specialized institutional support for measuring, analyzing and promoting productivity). The Japan Productivity Center was established in 1955 and the Asian Productivity Organization, a seven-country effort, was established a few years later in the early 1960's (19:22-23).

Not until President Nixon established the U.S. National Commission on Productivity by executive order in 1970, did the U.S. itself have such a specialized productivity agency. The executive order came as a result of a national productivity slump in the late 1960's. Since 1970 increased

national awareness of the importance of productivity improvement has accelerated the U.S. to a level more favorably comparable with other industrialized nations (19:24).

Traditional Definitions

Examination of productivity must begin with a definition of the concept. Lt Col Russell Lloyd, head of the AFIT School of Systems and Logistics Organizational Sciences Department, described productivity as "a concept that eludes easy definition [20]." This is illustrated by the many articles, books and papers on the subject. A few points, however, are repeated in most discussions of productivity. Terms such as efficiency, effectiveness, timeliness, quality, objectives, and ratios are integral to an understanding of the term productivity.

According to the American Productivity Center (APC) (23:4), the definition of productivity comes from the profit equation where:

$$\text{Profitability} = \text{Productivity} \times \text{Price Recovery} = \frac{\text{Output Quantities} \times \text{Prices}}{\text{Input Quantities} \times \text{Unit Costs}} \tag{1}$$

The APC says productivity is the output quantities divided by input quantities portion of Eq (1) whereas price recovery is the prices divided by costs. The APC believes there are two ways a firm can increase profit: "it can

produce more output per unit of input consumed or it can raise its prices faster than its suppliers are raising theirs [23,4]." However, this explanation ignores the possibility that a firm could decrease costs per unit input by increasing their productivity. Therefore, productivity could exclude output prices and instead be:

$$\text{Productivity} = \frac{\text{Output Quantities}}{\text{Input Quantities} \times \text{Unit Costs}} \qquad (2)$$

John W. Kendrick, in his book, Understanding Productivity, says: "Productivity is the relationship between output of goods and services and the input of basic resources --- labor, capital goods, and natural resources [19:1]." Kendrick further emphasizes that increased productivity is the chief means available to humanity to raise itself out of poverty to relative affluence (19:1). The idea of a relationship between inputs and outputs to a process is a central theme in studying productivity. Adam, Hershauer and Ruch, in their book Productivity and Quality, define productivity generically: "Productivity is a systemic concept concerning the conversion of inputs to outputs by the system under consideration [1:10]." Somewhat differently, Paul Mali defines productivity as "reaching the highest level of performance with the least expenditure of resources [21:6]." Mali attempts to incorporate all three ideas with this index ratio (21:7):

$$\text{Productivity Index} = \frac{\text{Output Obtained}}{\text{Input Expended}} = \frac{\text{Performance Achieved}}{\text{Resources Consumed}} = \frac{\text{Effectiveness}}{\text{Efficiency}} \quad (3)$$

Common to all the definitions is the relationship of outputs to inputs. However, in Eq (3) Mali implies, but never explicitly states, a quality judgment when he transforms "output obtained" into "performance achieved." Therefore, his transition to "effectiveness" over "efficiency" is hard to follow. The authors believe Mali's "output obtained" over "input expended" should result in an index of efficiency only and effectiveness should include other qualitative variables such as outputs not meeting engineering specifications, failing to perform, or delivered late.

Common productivity measures that are derived from ratios of outputs to inputs include the national productivity measures from the Departments of Labor, Commerce and Agriculture and are expressed as indexes. For a firm, outputs could be goods produced or services performed. Likewise, inputs could be labor employed, equipment used, or raw materials consumed. Outputs obtained over inputs expended are usually formed as index numbers, such as shirts produced per hour of labor. Usually, the index numbers must be compared to a base period. For example, it would not be practical to compare a firm's output profit over labor and machinery costs from one year

to the next without adjustments for inflation or the time value of money. Consequently, a base year or period should be established to adjust each year's index numbers.

From these definitions of productivity, one could think the study of productivity is concerned only with quantities of outputs per quantities of inputs. This may be the case if one uses the productivity measures primarily to improve efficiency or conserve resources. However, other dimensions such as quality and timeliness of outputs may apply. Adam, Hershauer and Ruch say: "There is no economic value in increased output levels if the increase is offset by lower quality [1:12]."

The concept of conserving resources is usually included in the discussions of efficiency. Quality and timeliness of the outputs are included in the concept of effectiveness. Including effectiveness measures in an analysis then requires a much larger data base. For this research effort, efficiency is defined as the ratio of the work done by an organism or machine to the energy supplied in the form of food or fuel. Effectiveness, on the other hand, is regarded as the same ratio but considers only the "useful" work done. Useful here refers to work that is of sufficient quality and done in acceptable time frames. Therefore, for the purpose of this research, productivity will be a measure of "useful" work done in the most efficient manner with emphasis towards measuring the technical efficiency of the AFLC maintenance function chosen for the modeling effort.

Military Definitions

The variety of productivity definitions in non-military sectors is mirrored in the military community. The Department of Defense (DOD) produrtivity directive is DOD Directive 5010.31, DOD Productivity Program, April 1979 and, together with DOD Instruction 5010.34, Productivity Enhancement and Evaluation - Operating Guidelines and Reporting Instructions, implements the DOD productivity program. In 1975, DOD directed each military department to establish a productivity program and designate an office responsible for planning, coordinating and representing the department on productivity matters (12). The Air Force's productivity regulation is AFR 25-3, Air Force Productivity Enhancement Program (PEP), dated 25 February 1982.

The DOD productivity program language emphasizes a technical, labor oriented view of productivity. For example, DOD Directive 5010.31 states:

> The DOD Productivity Program is a labor oriented program. Therefore, the primary basis for productivity assessment will be labor productivity measurement. . . . Where adequate cost information is available, total factor unit cost measures may be used in addition to labor based productivity measures [12:2].

Thus, economic as well as the partial technical measures of labor productivity are encouraged. Slightly different, the Air Force formal definition of productivity is:

> The measure of an organization's or function's performance. The efficiency or effectiveness with which resources (inputs) are used to accomplish a given mission (output) [11:9].

A further look at DOD definitions shows effectiveness measurement is a: "Comparison of current performance against pre-established mission objectives (goals) [13:10]." The Air Force believes effectiveness measurement "Compares actual results (output) to some pre-established organizational or functional objective or goal [12:9]." Here both DOD and Air Force definitions agree.

However, consider the definitions of efficiency measurement. The DOD concept of efficiency measurement is: "Comparison of current performance against either a pre-established standard or actual performance of a prior period [13:10]." The Air Force states efficiency measurement is: "The determination and comparison of the change in an organization's or function's output-input relationships for two or more periods of time [11:9]." These definitions mean the same thing; however, both fail to recognize that efficiency can be both a comparison of several similar units at a point in time or the same unit compared to itself over time.

John Kendrick, in Understanding Productivity, reinforces the authors' observations of the DOD and AF definitions with these comments:

> Others interpret the term (productivity) as always signifying the familiar output-per-man-hour ratio, whereas productivity may refer to the relationship of output to any or all of the associated inputs, nonhuman as well as human [19:12].

He further states that output increases may be a result of substituting other factors such as capital or some nonlabor inputs (19:13). Lastly, Kendrick makes another point relevant to an examination of DOD and Air Force productivity with:

> Occasionally, work measures are confused with productivity measures. But work measures relate actual output to a norm, or standard. They thus measure levels and changes in efficiency under a given technology. They (work measures) are not measures of productivity, which reflect changes in technology and other factors in addition to changes in labor efficiency as such. Finally, it must be noted that the level of a productivity ratio for any one period is not significant. Significance is derived from comparisons of the ratios for particular units, industries, or sectors over time (rate of change);... [19:13].

This analysis of military definitions of productivity suggests a broader perspective that both transcends a labor oriented view and a preoccupation with work measurements. A measurement technique capable of capturing all the factors suggested by Kendrick has yet to be developed. The next section analyzes several measurement techniques.

Measurements Analyzed

Productivity may be measured in many ways. A manager may choose partial or total ratios and employ statistical analysis, linear programming, heuristics or other techniques to analyze his firm. The goal should be to develop information that aids management decision making. The purpose of this section is to discuss the concepts of partial ratios, total measurement ratios and the DEA and CFA models and compare their advantages and disadvantages.

Productivity analysis involves measurement and evaluation and presupposes standards of performance (profitability and cost of production). While productivity analysis looks at the technical process of the firm (the conversion of inputs into outputs via a process), the management decisions that result will invariably affect profitability or costs.

According to Kendrick: "productivity analysis draws on many of the tools and concepts of microeconomics and macroeconomics, as well as on the institutional and analytical content [18:26]." Productivity analysis of a firm in the past has begun with the production function where quantity (Q) is a function of labor (L) and capital (C) or stated as $Q = f(L,C)$. Productivity might also be expressed as a ratio of output quantity over labor or capital (inputs) for each firm. Each firm is then compared to determine the most efficient firm. Additionally, productivity analysis might also compare a firm against

itself over a period of time.

Two factors have inhibited the practical use of Kendrick's concept. One, the "real" production function has always been unknown and could only be assumed. Two, firms could only be compared directly if their outputs were similar.

Partial Ratios. An easy productivity measurement to derive and understand is a partial productivity index of one output obtained over one input expended. An example of its usefulness can be shown by a comparison of two small firms, A and B. Firm A has five workers making ten shirts per hour, while Firm B has ten workers making 20 shirts per hour. Which firm is more productive? Using the productivity index formula, the ratio becomes the following where productivity equals:

$$\frac{\text{Outputs}}{\text{Inputs}} = \underset{\text{Firm A}}{\frac{10\ \text{Shirts}}{5\ \text{Workers}}} = \underset{\text{Firm B}}{\frac{20\ \text{Shirts}}{10\ \text{Workers}}} = \underset{\text{Index}}{\frac{2\ \text{Shirts}}{\text{Workers/Hour}}} \qquad (4)$$

Both firms are equally productive in Eq (4), even though one produces more shirts than the other. If Firm B loses two workers and still produces 20 shirts per hour, its productivity index would change to 20 shirts/8 workers or 2.5 shirts/worker/hour. This suggests Firm B would then be more productive than Firm A. Furthermore, by maintaining the same production rate after losing two workers, Firm B

has shown it possessed a surplus of workers in the first place or it changed to a more productive process.

To remain competitive, the manager of Firm A might wish to explore what caused Firm B to be more efficient so Firm A could benefit. There could be several reasons for the difference, such as room size, environmental conditions, or Firm B introduced a new technology. Also, the number and type of machines might be a factor. Therefore, a more accurate productivity measure would include all inputs and facets of production.

Total Factor Ratios. A disadvantage of using only partial measurements is that a manager's interest could be parochial allowing one area to improve and another to decline. The overall impact could be less than desired. Partial productivity measurements may give the manager some information on the effects of individual enhancements for parts of the firm, but most firms have many inputs and outputs. A total productivity ratio of all outputs over all inputs that evaluates the whole firm is needed. An example of a total ratio is this one by Mali (21:91):

$$\text{Total Factor Ratio} = \frac{\text{All Outputs}}{\text{Labor + Capital + Resources + Others}} \quad (5)$$

While an advantage of a total factor ratio is that it considers all outputs and inputs of a firm, a disadvantage is that each element of the inputs may influence the outputs

in different and unapparent proportions. For example, labor may affect the outputs more than capital, but this effect may not be recogn:zable in Mali's total factor ratio. Cowling and Stevenson explain another disadvantage as "the difficulties of disentangling technical change from the effects of scale economies and input substitution [10:7]."

One problem common to many total productivity measurement models is they do not aid management in their daily decision making process. Either the formats used in presenting the information are too detailed, making useful facts difficult to differentiate from irrelevant ones, or the reported results are so simplified only the most macro decisions are supported.

According to Barbara Pruett (22), Chief of the Productivity and Evaluation Division at HQ AFLC, this failure of productivity measurement models to support management decisions has frustrated HQ AFLC maintenance managers searching for an effective productivity measurement tool. Popular techniques such as the Navy Matrix Model, the American Productivity Center (APC) Model, and the Project 19 Model, developed at the AFLC Ogden Air Logistics Center Research Lab, Ogden, Utah, were considered and discarded by the HQ AFLC Productivity Measurement Working Group (22) because of their cumbersome use and failure to provide relevant data for decision making.

Data Envelopment Analysis and Constrained Facet Analysis. The Data Envelopment Analysis technique was developed by Charnes, Cooper and Rhodes for measuring efficiencies of organizations (6). Constrained Facet Analysis is an extension of the DEA model developed by Bessent, Bessent, Clark and Elam (5). A detailed explanation of both models is found in chapter 3; however, important here is the fact that both measure multiple inputs to multiple outputs simultaneously. According to Lt Col Charles Clark of the Air Force Institute of Technology (8:70-74), usefulness of DEA for efficiency evaluations has been demonstrated in the health care field, the public education field, the North Carolina judicial system, and the Navy recruiting field. All these fields are not-for-profit and have measurement difficulties similar to AFLC depot level maintenance. A major problem, when attempting measurements in not-for-profit organizations, occurs when outputs are in the form of "benefits" which are not as easily quantified as the outputs of an assembly line. The DEA and CFA models were selected for this research because they were developed specifically to satisfy the need for productivity measurement of not-for-profit organizations. Some of DEA and CFA advantages are:

1. They have proven useful in large, complex organizations.
2. They are capable of taking into account multiple inputs and multiple outputs simultaneously.

3. Information produced can directly support decision making at many management levels.

4. They are adaptable to networked computer operations connected with many geographically-separated centers.

The DEA and CFA models are largely untried in the Air Force environment. Because DEA and CFA have proven to be useful, state of the art techniques in other not-for-profit organizations, there may be many worthwhile ways of applying these techniques in AFLC and other Air Force organizations.

Summary

The U.S. has lagged behind other industrialized nations in productivity enhancement, particularly in the late 1960s. The Defense community has also been slow to develop cohesive productivity programs. AFLC, an early leader in Air Force enhancement efforts, has been hampered by a less than satisfactory productivity measurement capability.

Productivity is traditionally defined as some function of effectiveness and efficiency. For purposes of this research, effectiveness is combining all inputs into useful outputs. However, outputs not meeting organizational objectives for quantity, quality or timeliness are not considered useful. Efficiency is the conservation of input resources while producing a maximum number of outputs. The authors intend to measure technical efficiency within an AFLC maintenance area and assume outputs meet organizational effectiveness criteria.

DOD and Air Force regulations emphasize the technical, labor oriented view of productivity (i.e., output-per-man hour). This labor oriented view and many other popular productivity measurements before the DEA and CFA techniques were a collection of simple output to input ratios called partial ratios. Partial ratios are easy to derive and understand but limit the analysis to only one area of a firm. However, a total factor ratio evaluates the whole firm by considering all outputs and inputs, but may not account for the interactivity of inputs and outputs measured simultaneously.

The DEA and CFA techniques have demonstrated their usefulness in efficiency evaluation in many not-for-profit organizations. Their advantages over partial and total factor ratios are DEA and CFA measure multiple inputs and multiple outputs simultaneously, account for the interactions of the variables and produce information that directly supports management decision making. The following chapter presents a detailed explanation of the DEA and CFA models and their characteristics.

III. Methodology

Introduction

Chapter I includes a list of the five research objectives for this thesis. The first objective, (1) to define productivity for AFLC depot-level maintenance, was met with the literature review in Chapter II. This chapter accomplishes objectives two and three which are: (2) to establish criteria to select input and output measurements, and (3) to develop the relationship between selected inputs and outputs using DEA and CFA. The groundwork for objective four, (4) to evaluate the DEA and CFA models using AFLC data, begins in Chapter IV and is concluded in Chapter V. Objective five, (5) to suggest appropriate Air Force DEA and CFA applications, is met in Chapter VI.

Development of the methodology starts with an explanation of how DEA and CFA models work and is followed by a description of the data selection criteria. Next, the data source and the process of extracting the inputs and outputs used in the model are presented along with data limitations. This is followed by a discussion of the modeling exercise that details the various combinations of inputs and outputs that are compared and analyzed. Finally, the types of information the model should produce are discussed.

How DEA and CFA Analyses Work

Data Envelopment Analysis. DEA analysis uses linear fractional programming and requires computer resources for most applications. With linear fractional programming, DEA can evaluate multiple inputs and outputs simultaneously and take into account the interactive relationships. In simple problems (two inputs and one output), a DEA analysis can be displayed on a Cartesian Coordinate graph. However, when considering more than one output and two inputs, although the technique applied is the same, it becomes impossible to graphically display the multiple dimensions. Also, the multi-dimensional mathematics are laborious without the aid of a computer.

The DEA model is expressed in the following mathematical form according to A. Bessent and E. Bessent of University of Texas (3,59):

Objective Function

$$\text{Maximize } h = \sum_{r=1}^{s} u_r \; y_{ro} \Big/ \sum_{i=1}^{s} v_i \; x_{io}$$

Constraints

$$\sum_{r=1}^{s} u_r \, y_{rj} \Big/ \sum_{i=1}^{m} v_i \; x_{ij} \leq 1 \quad \text{for} \quad j = 1,\ldots,n$$

$$u_r, \; v_i, \; y_{rj}, \; x_{ij} > 0$$

where:

y_{rj} = measurement of rth valued output for decision making unit (DMU) j
x_{ij} = measurement of ith input for DMU j
u_r = weight for output r to be calculated from the analysis
v_i = weight for input i to be calculated from the analysis (6)

A decision making unit (DMU) is an organizational element being analyzed. For instance, if an analysis compares 35 warehouses, each warehouse would be a DMU. An alternate method would be to compare the same warehouse to itself over time by making periodic observations where each observation is treated as a DMU. DMUs have similar observed input and output measures represented by y and x values in the equation. The values u and v are unbiased weights (also

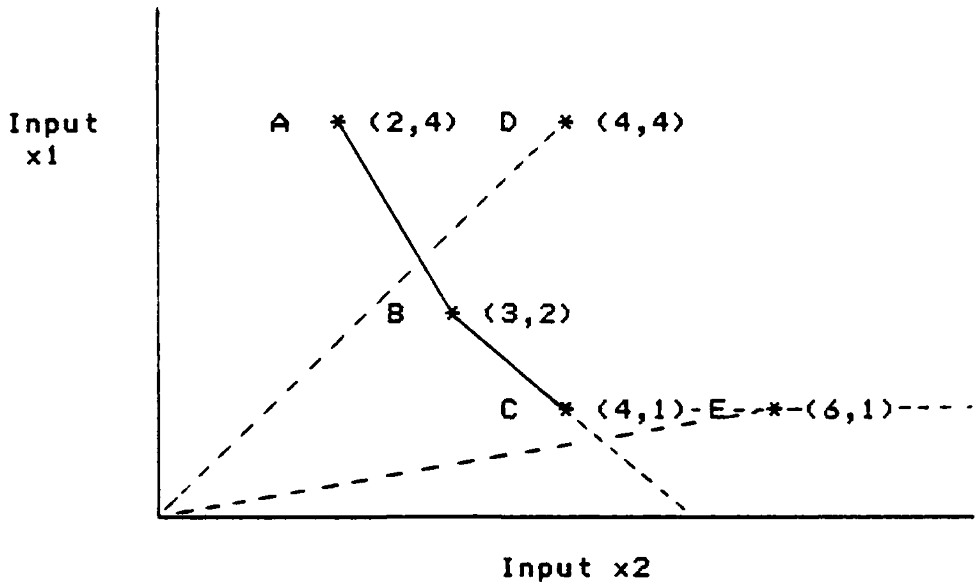
referred to as multipliers in some references) derived from the model calculations.

It is important to understand the specific difference between the terms efficient and inefficient. Charnes, Cooper and Rhodes (6:669) define DMU efficiency as:

> i. Output Orientation: A DMU is not efficient if it is possible to augment any output without increasing any input and without decreasing any other output.
>
> ii. Input Orientation: A DMU is not efficient if it is possible to decrease any input without augmenting any other input and without decreasing any output.

These definitions are accepted as consistent with the definition of efficiency as stated in the summary of Chapter II and operationalize efficiency for purposes of this research.

According to Bessent and Bessent, DMU efficiency analysis starts when "all units are compared in order to locate the best ones in the set and to use these as the criterion of efficiency [3:60]." The following graph of a single output, two input case illustrates how DEA analysis works. This example was first presented by Clark in his dissertation (8:30).



Unit	Input x1	Input x2	Output
A	2	4	1
B	3	2	1
C	4	1	1
D	4	4	1
E	6	1	1

Figure 1. How DEA and CFA Work

Figure 1 represents five DMUs with different mixes of input quantities producing the same output quantity. The output quantity for each is displayed as identical because the single output DEA solution is equivalent to scaling all DMU outputs to a single quantity and proportionally reducing all DMU inputs. A "piece-wise linear frontier" is formed by connecting points A, B and C (DMUs closest to the origin).

This curve represents the most efficient DMUs and is called the relative efficiency frontier. Each DMU on the frontier produces the same output with fewer quantities of inputs x1 and x2 than any DMU not on the frontier. DMUs on the efficiency frontier are considered by DEA to be 100% efficient. However, DEA 100% efficiency is not absolute but is the rating given to the best of the observed DMUs with no assumption of an ideal production function.

The model next compares the inefficient DMU represented by point D (4,4) to the segment of the frontier between A and B. This is done by extending a ray from the origin (0,0) to point D. The unit's efficiency is a ratio of the length of the line segment from the origin to the intersection of the frontier segment (A to B) divided by the entire length of the ray from the origin to D. In this example the efficiency ratio is 67%. This also illustrates the "envelopment" characteristic of the model where point D is compared to the empirically-derived frontier segment between A and B because the line from the origin to D passes through that portion of the frontier.

The efficiency rating of point D is derived <u>without</u> comparison to any other points but A and B, illustrating another important aspect of DEA analysis. Inefficient DMUs are directly compared only to DMUs on the efficiency frontier which have similar mixes of inputs and outputs. According to Barbara Pruett, overcoming the tendency to compare dissimilar activities would be an advantage of using

DEA productivity analysis in AFLC management decision making (22).

Constrained Facet Analysis. A. Bessent and others (5) extended the use of DEA analysis with Constrained Facet Analysis (CFA). This technique explores the efficiency of points like E (6,1) in Figure 1, which lies outside the frontier envelope. Referring to Figure 1, CFA computes a lower bound of efficiency by creating a downward sloping extension of the frontier from point C to the x2-axis and an upper bound of efficiency by creating an horizontal frontier extension parallel to the x2-axis from point C. The efficiency of point E is then computed like point D, except that two efficiency ratings are derived from the two imaginary frontiers. True efficiency for point E is assumed to be bounded by the two resulting efficiency ratings. In Figure 1, the efficiency boundaries of point E are 100% efficient and 71% inefficient. In this way, all DMUs can be evaluated, although for points like E a range of efficiency is provided.

Another aspect of CFA is the in-depth analysis of neighborhood portions of the frontier. Several DMUs clustered together in an area of a graph (such as points A, B and D in Figure 1) are considered a "neighborhood" according to Clark (9). Specific actions that would move an inefficient DMU to the efficiency frontier can be explored by examining the characteristics of the DMUs in the neighborhood. Since points A and B are considered efficient

and in point D's neighborhood, point D should be able to improve to an efficiency level comparable to A and B.

Summary of DEA and CFA Characteristics. DEA and CFA productivity analyses have many characteristics important to organization managers (9). Some are:

1. A frontier of efficiency is built based on empirical data instead of assuming an ideal production function (such as an economic isoquant).

2. All aspects of the organization can be measured simultaneously, capturing trade-offs and interactions between inputs and outputs.

3. All DMUs are rated efficient or inefficient. If the DMU has a unique input/output mix and is identified as an outlier, it is still rated with estimates of efficiency boundaries.

4. In addition to rating all DMUs, individual DMU inputs and outputs are rated for their contribution to a DMUs efficiency rating. This helps pinpoint and prioritize corrective actions for inefficient DMUs.

5. Value judgments or *a priori* weights are not assigned to inputs or outputs for DEA or CFA calculations. Weights or multipliers appearing in the analysis results are produced by the models.

6. DMUs rated inefficient by DEA or CFA are assigned the highest possible efficiency rating. This gives the "benefit-of-the-doubt" about measurement error to the individual DMU, reducing reluctance to measurement.

7. DMUs are compared only to similar, efficient DMUs. This reduces the possibility of trying to compare "apples and oranges".

Data Collection

Air Logistics Center Selection. The Sacramento Air Logistics Center (SMALC) was selected for the modeling effort. Hq AFLC maintenance productivity managers (22) suggested the SMALC center over the other four centers for the following reasons:

1. SMALC is "typical" of AFLC depot-level maintenance activities. Its size and complexity suggest successful adaptation of DEA and CFA to this center should make the techniques adaptable to other centers.

2. Several of the individual SMALC maintenance functions have produced the same types of items over several years making analysis of a function over a period of time meaningful.

The authors agreed with Hq AFLC because the SMALC selection conformed to a DEA modeling assumption that organizational expertise should be an active element in the input and output selection process (3).

Roger P. Dwyer, Chief of the Financial Management Section, SMALC Resources Management Division (14), was asked to select a "typical" SMALC shop for study. Dwyer selected the Pneudraulic Motor and Miscellaneous Units Resource

Control Center (RCC) and provided sample data. This RCC (hereafter referred to as the hydraulic shop) repairs hydraulic assist components of C-130, KC-135 and other multi-engine transport aircraft. The hydraulic shop has an experienced and stable work force that repairs about 100 types of components per fiscal year. Inputs to the repair process are the components, repair parts and materials, capital investments (machinery and shop space), utilities, labor and miscellaneous administrative expenses. Dwyer's choice of the hydraulic shop was also ideal because shop activities were extensively documented.

Two types of analysis were considered: (1) comparison of the hydraulic shop to other similar shops, and (2) the hydraulic shop compared to itself over time. Since the hydraulic shop has unique outputs compared to other SMALC shops, the authors decided to compare the hydraulic shop to itself over time.

Inputs and Outputs Selected. According to Clark, input and output candidates should have logical appeal (9). For example, to be a logical input candidate, an increase in an input quantity should have the effect of increasing one or more outputs. Organizational goals and the advice of local managers should also be considered when selecting inputs and outputs. Finally, to maintain acceptable levels of accuracy, the sum of the numbers of inputs and outputs used in the analysis should be about one half the number of DMU observations (9).

The input and output data were taken from Hq AFLC Data Collection Forms G035A and G019C for fiscal years 1981 through 1983 (samples are shown in Appendix B). Input and output values were actual dollar amounts and hours recorded for the hydraulic shop. The Form G035A data (inputs) were recorded monthly. However, the Form G019A data (outputs) were in quarterly form. Because of this, the output data limited the DEA model to 12 DMUs representing the 12 quarters of three consecutive fiscal years. The 12 DMUs were not an ideal number (only six or seven variables could be measured simultaneously), but enough to demonstrate the DEA and CFA techniques. If output data were captured monthly instead of quarterly, the number of inputs and outputs measured would be about 18 (half the 36 months). Also, if the hydraulic shop analysis became an ongoing effort, each additional quarter of data would allow more inputs and outputs to be measured simultaneously, providing increasingly more detailed information on shop efficiency.

Working with Dwyer (14), the authors selected four input and five output candidates. Since only a maximum of six or seven candidates could be considered in each analysis version, many combinations of these variables were analyzed to identify the important relationships. These combinations are described later in this chapter.

The monthly input figures were summed to make quarterly values. Fiscal Year 1981 was established as the base year and inflation adjustments were applied to Fiscal Years 1982 and 1983.

Inputs. The four inputs selected were actual shop activity hours, labor dollars, material dollars and "all other" dollars (administrative and miscellaneous). These inputs were derived from the G035A forms in the following manner:

1. Shop activity hours were taken directly from the forms.

2. Labor dollars were a combination of direct and indirect labor dollars.

3. Material dollars were a combination of direct and indirect material dollars.

4. All other dollars were calculated by subtracting labor and material dollar quantities in two and three above from the total dollar expenditure figures.

Sample calculations are presented in Figure 2. The values of were taken from the sample hydraulic shop data in Appendix B. Specifically, all values were taken from the second column under the heading "Actual".

1. Labor Hours

2,912.9

2. Labor Dollars

Direct Labor	=	41,368.88
+Indirect Labor	=	+ 5,579.01
Labor Dollars	=	46,947.89

3. Material Dollars

Direct Materials	=	153,407.07
+ Indirect Materials	=	+ 3,380.66
Material Dollars	=	156,787.73

4. All Other Dollars

Total Cost	=	227,581.22
- Labor Dollars	=	- 46,947.89
- Material dollars	=	- 156,789.73
All Other Dollars	=	23,843.60

Figure 2. Sample Calculation of Input Variables from Appendix B Data

Outputs. Because there were about 90 different output items per quarter, a method of combining the totals was devised. Since the portion of quarterly shop direct labor hours dedicated to individual outputs was recorded, the formula in Figure 3 was used to assign an output quantity for each item. A sample calculation is shown in Figure 3 using values of one output item (pump 4320001623917HS)

extracted from the Form G019A shown in Appendix B. The circled numbers represent, (1) the time the shop was credited for its part of the repair and (2) the number of units repaired. For this item, the shop hours times the number of units repaired per quarter was the output quantity for quarter 1 of 1983. The similarly computed output quantity for each of the approximately ninety items (see Appendix C for each item's output quantity) was then summed for a total output quantity for the hydraulic shop per quarter. These quarterly output quantities were used in the single output model.

Another model tested was a partial output model that considered only those individual outputs with a cumulative output quantity of 1000 or more for the three year period. Ignoring the individual outputs of less than 1000, the totals were calculated the same as the single output model. This model was intended to show managers useful results can be obtained with only significant portions of the outputs considered.

Also, a multiple output model was derived by considering the output quantities of the two individual items with the highest output quantity for the three year period separately and then summing the remaining individual outputs for a third quantity. In this way both the single and multitple output models account for all output per quarter.

Figure 3 is an example of an individual output quantity calculation.

Shop Direct Activity Hours	X	Number of Items Repaired	=	Output Quantity
5.7 Hours	X	5 Items	=	28.5 Units of Output

Figure 3. Sample Calculation of Output Quantities from Appendix B Data

Testing the Models

Three models (single output, partial output and multiple output) were formulated to analyze the hydraulic shop, using input data with dollar values as recorded and adjusted for inflation. Table I (page 36) shows the resulting ten tests. The authors hypothesized that with each model, the version using input data adjusted for inflation would indicate higher productivity in 1982 and 1983 quarters (1981 was the base year and not adjusted). Also, it was hypothesized that of the four inputs, two (labor hours and dollars) would account for the same resource, labor. To evaluate this possibility, single output tests were formulated using first labor hours and then labor dollars as the labor resource (Tests 3 through 6).

The authors also hoped to show additional capabilities of DEA and CFA analyses. Tests 7 and 8 (partial output model) used data only from 26 of the 93 individual outputs

when the criterion of a cumulative output quantity of 1000 or more was considered. These tests were designed to show that useful results could be obtained if only the most repaired items were evaluated. Tests 9 and 10 were formulated to evaluate the multiple output model. It was hoped that diagnostic information about individual items of repair could be shown.

TABLE I

The Tests

Inputs	One Output (all components combined)	One Output (top 26 combined)	Three Outputs (top 1 & 2 + all others)
All Inputs No Inflation Adjustment	Test 1	Test 7	Test 9
All Inputs With Inflation Adjustment	Test 2	Test 8	Test 10
No Labor Hours No Inflation Adjustment	Test 3		
No Labor Hours With Inflation Adjustment	Test 4		
No Labor Dollars No Inflation Adjustment	Test 5		
No Labor Dollars With Inflation Adjustment	Test 6		

Summary

In this chapter DEA and CFA analyses were explained and illustrated with an example (Figure 1). The piece wise linear frontier and efficiency calculations were explained in detail to show that DEA efficiency ratings are relative and based on the empirical data. In addition, CFA, an extension of the DEA technique, provides a lower bound of efficiency for inefficiently rated DMUs and more detailed analysis of neighborhood DMUs.

Data collection methods and rational were explained. The process of selecting inputs and outputs was described as was the formulation of the three models. Finally, the ten tests of the models and the rationale for each test were discussed along with some of the expected results. The following chapter presents the analysis of each test.

IV. Analysis

This chapter presents the analysis of each test formulated in the previous chapter and is divided into three parts: the single output model, the partial output model, and the multiple output model. An analysis of the individual models is presented in each part and an overall analysis of the modeling exercise is presented in the summary at the end of the chapter. However, before the three major output models are addressed, a brief discussion of computer resources and the data base is presented.

Computer Softwares and Hardware

To incorporate the features of both techniques, the DEA and CFA calculations were combined into one computer program. The DEA model was employed first to find all efficient DMUs and the upper bound of efficiency for the inefficient DMUs that were not frontier units (rated less than 1.0 efficient). Then, CFA was employed to establish a lower bound of efficiency for the inefficient DMUs. This allowed each DMU to be rated efficient or inefficient within some upper and lower bound.

The computer softwares used were derived from routines developed by researchers at the University of Texas (UT) using a CDC CYBER, mainframe computer. The softwares were adapted to an International Business Machines Personal

Computer (IBM PC), mini class computer by Captain John Fraser, a fellow graduate student (15). This use of the IBM PC was possible because the number of inputs and outputs from the hydraulic shop was small (seven variables). The specific machine used was an expanded IBM PC equipped with 512,000 (512K) bytes of memory, a 10 megabyte harddisk, 2 floppy disk drives and an 8087 IBM numeric processor. The softwares were written in the BASIC computer language and executed in the compiled version. Although the IBM PC had a large memory capacity, a standard 64K personal computer could have provided the same results for this research but at a slower pace.

The Data Base

Input Values. Tables II and IV (pages 40 and 42 respectively) show the input quantities used to evaluate the hydraulic shop. Table II shows the values of input hours and dollars with no adjustments for inflation. Table III (page 40) shows the inflation factors used to adjust the 1982 and 1983 dollar values to the base year, 1981. The inflation factors originated at the Office of the Secretary of Defense for Proposed Budget and Sales and were provided by Hq AFLC (22). Table IV dollar values reflect the inflation adjustments.

TABLE II

Inputs Not Adjusted for Inflation

Observed Quarter	Labor Hours	Total Labor Dollars	Total Material Dollars	All Other Dollars
1981				
1	6,691	107,506	391,058	68,001
2	7,358	118,127	502,578	79,941
3	7,907	129,197	585,656	65,046
4	7,534	124,016	471,364	56,482
1982				
5	6,979	138,725	711,876	78,649
6	8,165	141,960	583,037	83,902
7	10,134	196,975	945,082	114,295
8	8,958	166,159	1,081,340	93,634
1983				
9	7,148	132,931	888,811	88,876
10	9,121	149,942	1,228,537	108,818
11	7,396	139,392	1,382,716	97,966
12	8,809	145,555	1,114,040	99,601

The 1982 labor dollars were reduced by 5.5 percent in observed quarters 7 through 10 because Sacramento Air Logistics Center payroll increases were not effective until April, the beginning of the third quarter of the fiscal year. Observed quarters 11 and 12 were first reduced by 5.0 percent for 1983's inflation and then by 5.5 percent for 1982's inflation to arrive at a 1981 base year labor dollar fiqure. Similarly, material dollars and all other dollars were reduced by Table III's inflation factors for each year.

TABLE III

Inflation Factors Applied to Inputs

Variable	1982 Percentage	1983 Percentage
Total Labor Dollars	5.5 %	5.0 %
Total Material Dollars	10.2 %	13.6 %
All Other Dollars	11.5 %	6.1 %

The following example of cross multiplication demonstrates how inflation adjustment calculations were made using 1982 Total Labor Dollars from observed quarter 7 (Table II) and applying the 1982 labor inflation factor (Table III) to compute inflation adjusted Total Labor Dollars for observed quarter 7 (Table IV).

$$\frac{\text{Quarter 7 Total Labor Dollars}}{\$\ 196{,}975} = \frac{100 \text{ percent}}{105.5 \text{ percent inflation}}$$

$$\text{Quarter 7 Total Labor Dollars} = 186{,}706 \qquad (7)$$

The next example demonstrates how inflation adjustment calculations were made using 1983 Total Labor Dollars from observed quarter 11 (Table II) and applying the 1982 and 1983 labor inflation factors (Table III) to compute inflation adjusted Total Labor Dollars for observed quarter 11 (Table IV).

$$\frac{\text{Quarter 11 Total Labor Dollars}}{\$\ 139{,}392} = \frac{100 \text{ percent}}{105 \text{ percent inflation}}$$

$$\text{Quarter 11 Total Labor Dollars} = 132{,}754$$

$$\frac{\text{Quarter 11 Total Labor Dollars}}{\$\ 132{,}754} = \frac{100 \text{ percent}}{105.5 \text{ percent inflation}}$$

$$\text{Quarter 11 Total Labor Dollars} = 125{,}833 \qquad (8)$$

TABLE IV

Inputs Adjusted for Inflation

Observed Quarter	Labor Hours	Total Labor Dollars	Total Material Dollars	All Other Dollars
1981				
1	6,691	107,506	391,058	68,001
2	7,358	118,127	502,578	79,941
3	7,907	129,197	585,656	65,046
4	7,534	124,016	471,364	56,482
1982				
5	6,979	138,725	645,985	70,537
6	8,165	141,960	529,072	75,248
7	10,134	186,706	857,606	102,507
8	8,958	157,497	981,252	83,977
1983				
9	7,148	126,001	709,986	75,127
10	9,121	142,125	981,360	91,983
11	7,396	125,833	1,104,518	82,810
12	8,282	131,397	889,899	84,193

Output Values. Tables V, VI and VII (pages 43, 55 and 59, respectively) show the output values used to evaluate the hydraulic shop. Table V shows the output values for the single output model (Tests 1 through 6) which are total output quantities for each observed quarter. Table VI (shown in Part II) shows the output values for the partial output model (Tests 7 and 8), which are totals of the top 26 items (with an output quantity of 1000 or more for all three years) repaired by the hydraulic shop. Table VII (shown in Part III) shows the output values for the multiple output model (Tests 9 and 10).

Part I. Single Output Model

This portion addresses the results and analysis of the single output model (Tests 1 through 6) using the output data from Table V (see below). For each test, a graphical display of the results appears showing the upper and lower bounds of efficiency for each observed quarter (DMU). The upper and lower bounds of efficiency are displayed on the top two curves and the total output quantity on the single curve below. The reader should note the double scale on the vertical axis of the left side of each graph. The decimal value scale is associated with the two efficiency lines on the top part of the graph, while the other scale is associated with output quantities (value times 1000) shown as the bottom line of the graph.

The following table shows the single output quantities for Tests 1 through 6.

TABLE V

Output Quantities for Tests 1 - 6

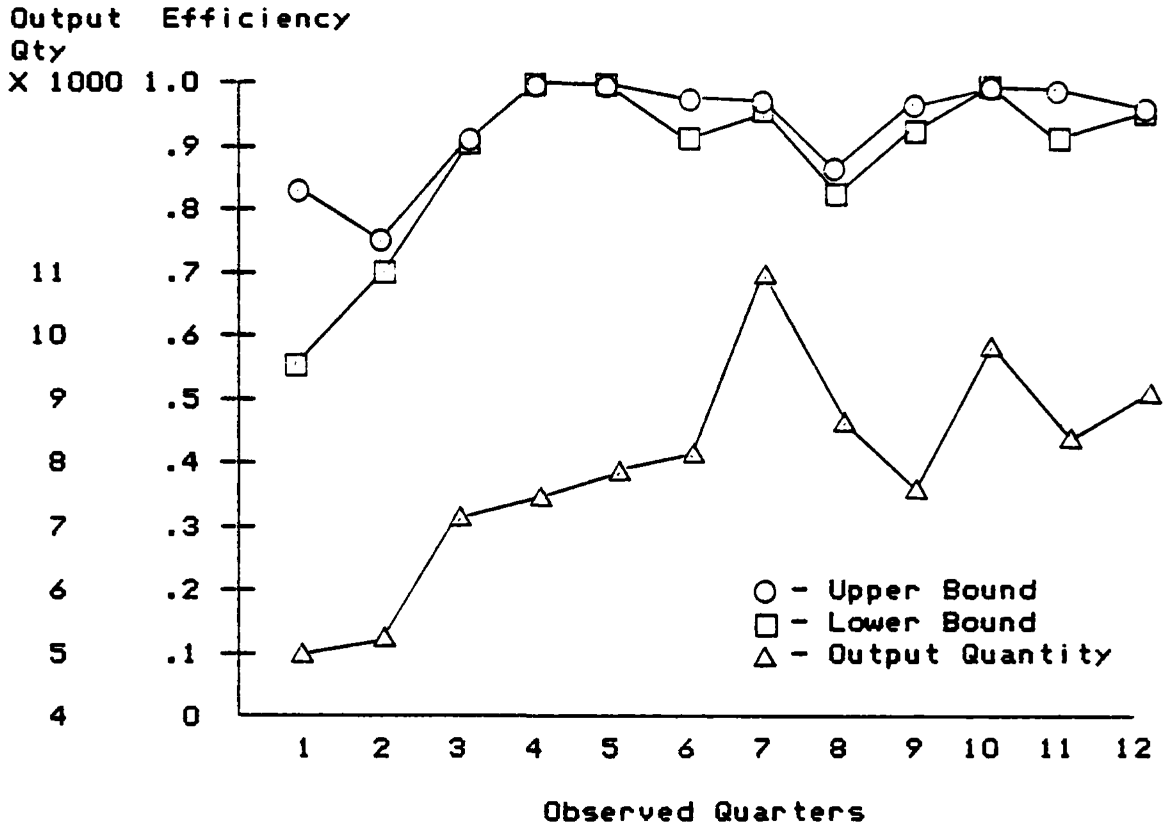
Observed Quarter	Output Quantity	Observed Quarter	Output Quantity
1981			
1	4,967.7	7	10,823.5
2	5,335.8	8	8,416.0
3	7,024.4	1983	
4	7,283.8	9	7,581.1
1982		10	9,742.7
5	7,840.8	11	8,165.0
6	8,028.7	12	8,837.2

Test 1 Analysis. The authors considered Test 1 the most comprehensive test of the DEA and CFA technique in this research project for two reasons. First, the model includes all inputs and accounts for all the hydraulic shop production in a single output. Second, since no adjustments were made for inflation, the model was permitted to evaluate purely observed values while taking into account all the interactions and trade-offs including the increasing costs of resources. On the other hand, when eroding buying power from one fiscal year to the next is considered, this model may not accurately represent the dollar value of labor effort or volume of material resources.

Looking at the DEA and CFA results in Figure 4, observed quarters 1 and 2 are the least efficient and observed quarters 4, 5 and 10 are the frontier units (1.0 rating). The quarter with highest output, observed quarter 7, is not the most efficient but does show a dramatic increase in input and output with only a slight loss in efficiency of 2 percent from the frontier DMUs. This suggests that slightly more inputs were used in observed quarter 7 than were needed for the higher output. This result, combined with the relatively low efficiency ratings and low production levels of observed quarters 1 and 2, suggests a reserve production capacity that cannot be easily reduced when production demands are low. This reserve capacity is likely attributed to the fixed assets such as the permanent work force, administrative costs and capital

investments. The management actions necessary to achieve the high output in observed quarter 7 may also have contributed to the lower efficiency rating in observed quarter 8. The after effects of a production surge, a residual temporary work force, or unused materials may have lowered the efficiency rating.

Observed quarters 4, 5 and 10 should be considered good examples of the proper mix of inputs for the respective outputs. Since lower efficiency ratings suggest less efficient use of resources, management should look for ways to improve this use. The results do not suggest seasonality trends in efficiency. However, when considering the upper bounds of efficiency for each year, a trend does develop that suggests a general increase in efficiency from the beginning to the end of the test period.

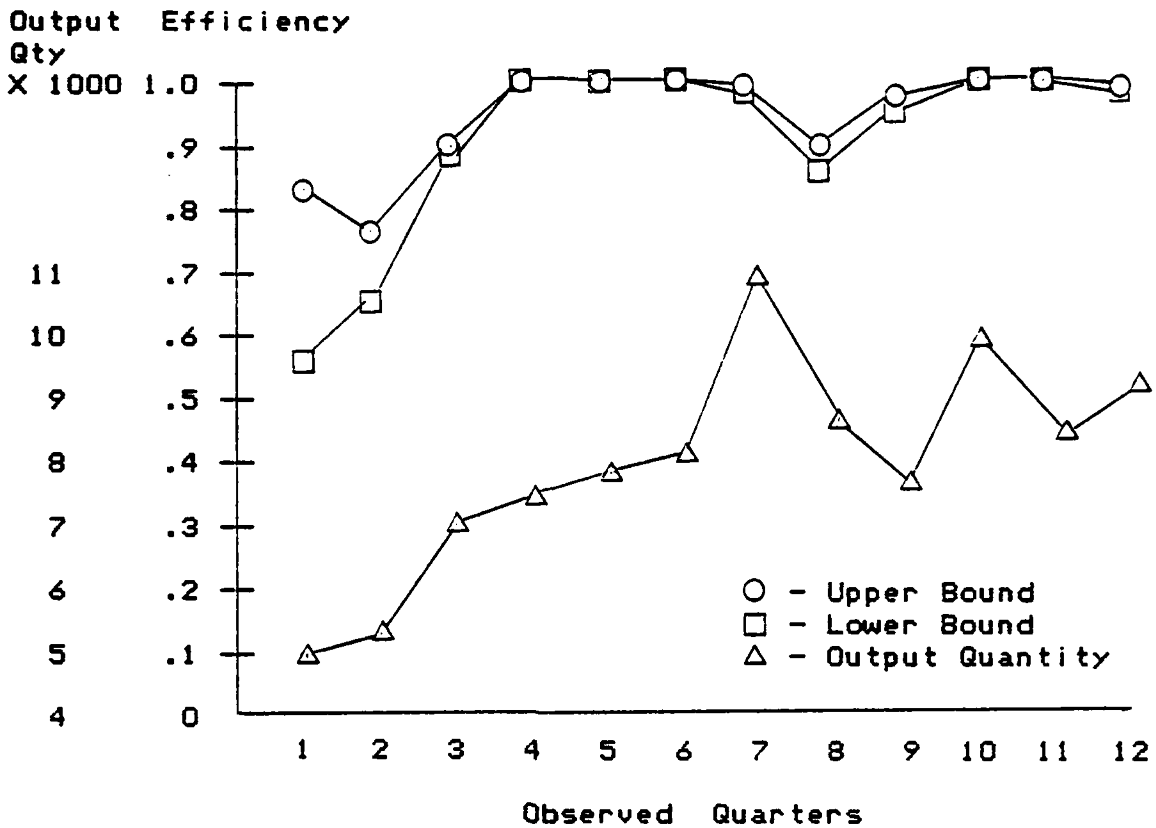


Observed Quarter	Lower Bound	Upper Bound	Output Quantity
1981			
1	.566	.822	4967.7
2	.700	.761	5335.8
3	.906	.910	7024.4
4	1.000	1.000	7283.8
1982			
5	1.000	1.000	7840.8
6	.909	.981	8028.7
7	.950	.981	10823.5
8	.845	.872	8416.0
1983			
9	.944	.962	7581.1
10	1.000	1.000	9742.7
11	.910	.997	8165.0
12	.947	.950	8837.2

Figure 4. Test 1, One Output, Inputs Not Adjusted for Inflation.

Test 2 Analysis. As hypothesized, the input adjustments for inflation improved the efficiency ratings for 1982 and 1983, observed quarters 5 through 12. Observed quarters 4, 5 and 10 remain on the frontier (1.0 rating) while two more efficient observed quarters, 6 and 11, are added to the frontier. The overall efficiency improvement in the later observed quarters makes intuitive sense because it now takes less input resources (measured by dollars) to produce the same output. The first three observed quarters are affected only slightly by the inflation adjustment and retain their relative positions to the others. This test could be considered the most accurate if the inflation adjustments correctly represent the real dollar values of labor and material resource inputs.

A trend of improvement is found in both Test 1 and 2. When averaging the upper bounds of efficiency for each year, each year's efficiency increases. This strongly suggests management converted resources into output more efficiently in 1982 and 1983 than in 1981.

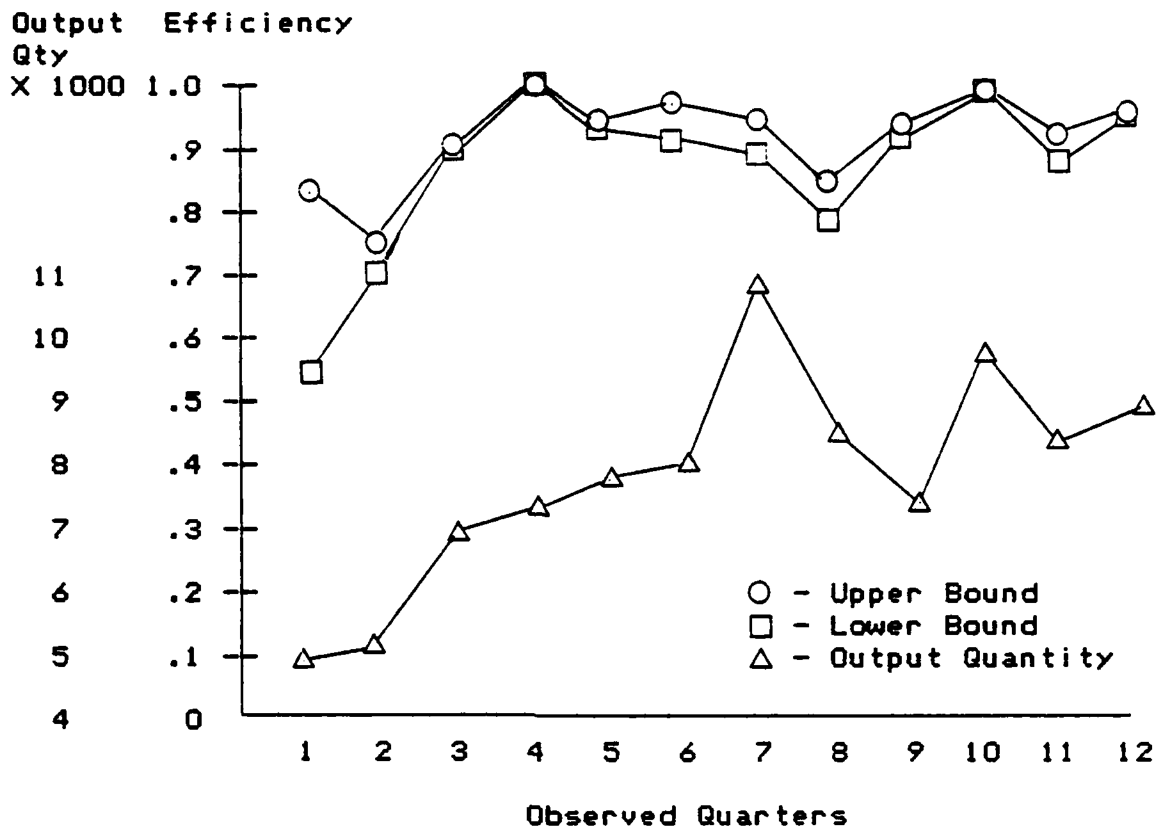


Observed Quarter	Lower Bound	Upper Bound	Output Quantity
1981			
1	.566	.822	4967.7
2	.645	.751	5335.8
3	.891	.893	7024.4
4	1.000	1.000	7283.8
1982			
5	1.000	1.000	7840.8
6	1.000	1.000	8028.7
7	.966	.998	10823.5
8	.840	.884	8416.0
1983			
9	.953	.972	7581.1
10	1.000	1.000	9742.7
11	1.000	1.000	8165.0
12	.968	.987	8837.2

Figure 5. Test 2, One Output, Inputs Adjusted for Inflation.

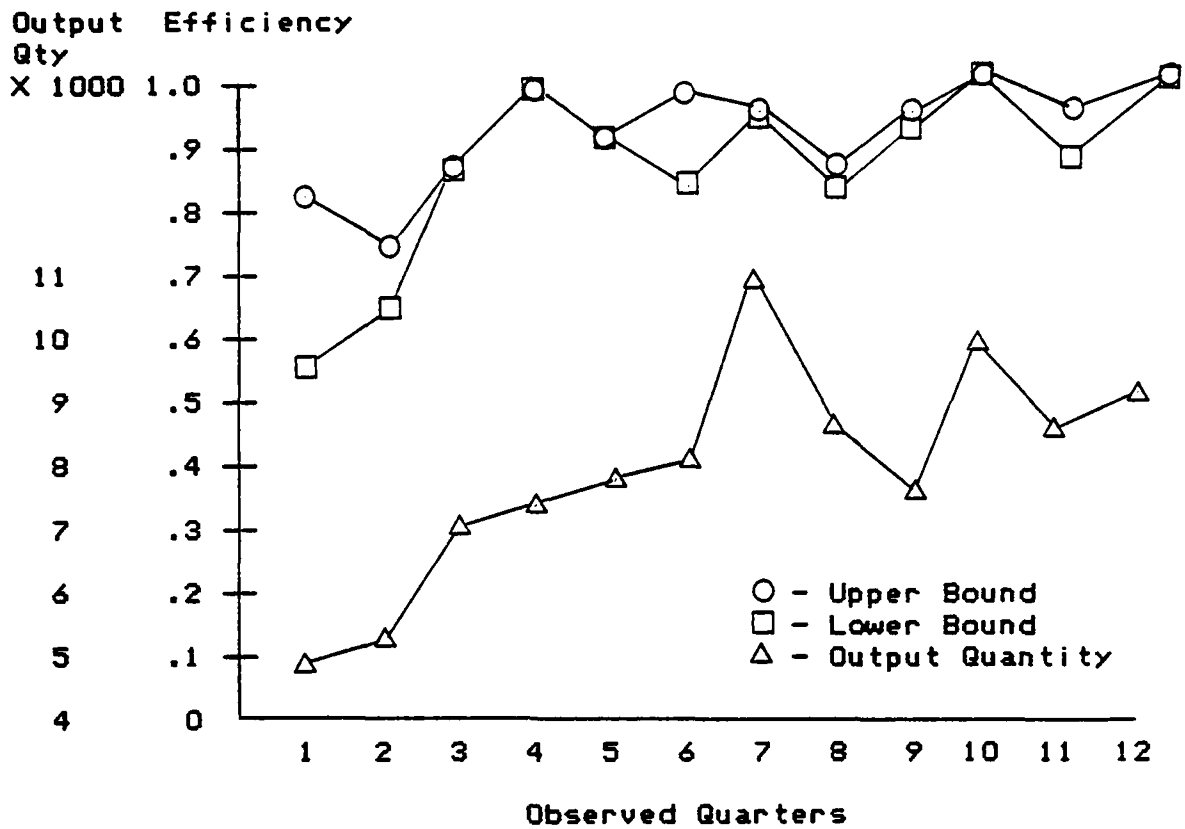
Tests 3 and 4 Analysis. Tests 3 and 4 evaluated one output and three inputs that excluded the labor hours input. Test 4 was accomplished using inflation adjusted input data. The inflation adjustment had the same general effect as in Tests 1 and 2. The efficiency ratings for the 1981 observed quarters were slightly changed while the efficiencies of the 1982 and 1983 observed quarters improved. Additionally, the average yearly upper bounds of efficiency increased as in Tests 1 and 2.

However, there is a difference from the first two tests. The effects of excluding the labor hours input on observed quarters 5, 6 and 11 illustrates the benevolence of the DEA and CFA techniques. Observed quarters 6 and 11 do not move to the frontier from Test 3 to Test 4 and observed quarter 5 is not rated as a frontier unit in either Test 3 or 4. With Tests 1 and 2, the more inefficiently used inputs were ignored in the calculations as the model worked to award the highest possible efficiency ratings. By removing labor hours the model is forced to consider labor dollars, a sometimes less efficiently used resource. This results in lower efficiency ratings for some DMUs; however, the general relationships of the 12 DMUs are preserved. A possible explanation for the two models arriving at different results could be that the allocation of labor costs to the hydraulic shop and the shop's process of recording labor hours are somewhat independent.



Observed Quarter	Lower Bound	Upper Bound	Output Quantity
1981			
1	.566	.822	4967.7
2	.708	.761	5335.8
3	.909	.910	7024.4
4	1.000	1.000	7283.8
1982			
5	.922	.932	7840.8
6	.914	.956	8028.7
7	.892	.914	10823.5
8	.809	.827	8416.0
1983			
9	.896	.908	7581.1
10	1.000	1.000	9742.7
11	.869	.909	8165.0
12	.946	.948	8837.2

Figure 6. Test 3, One Output, Inputs Not Adjusted for Inflation with No Labor Hours.

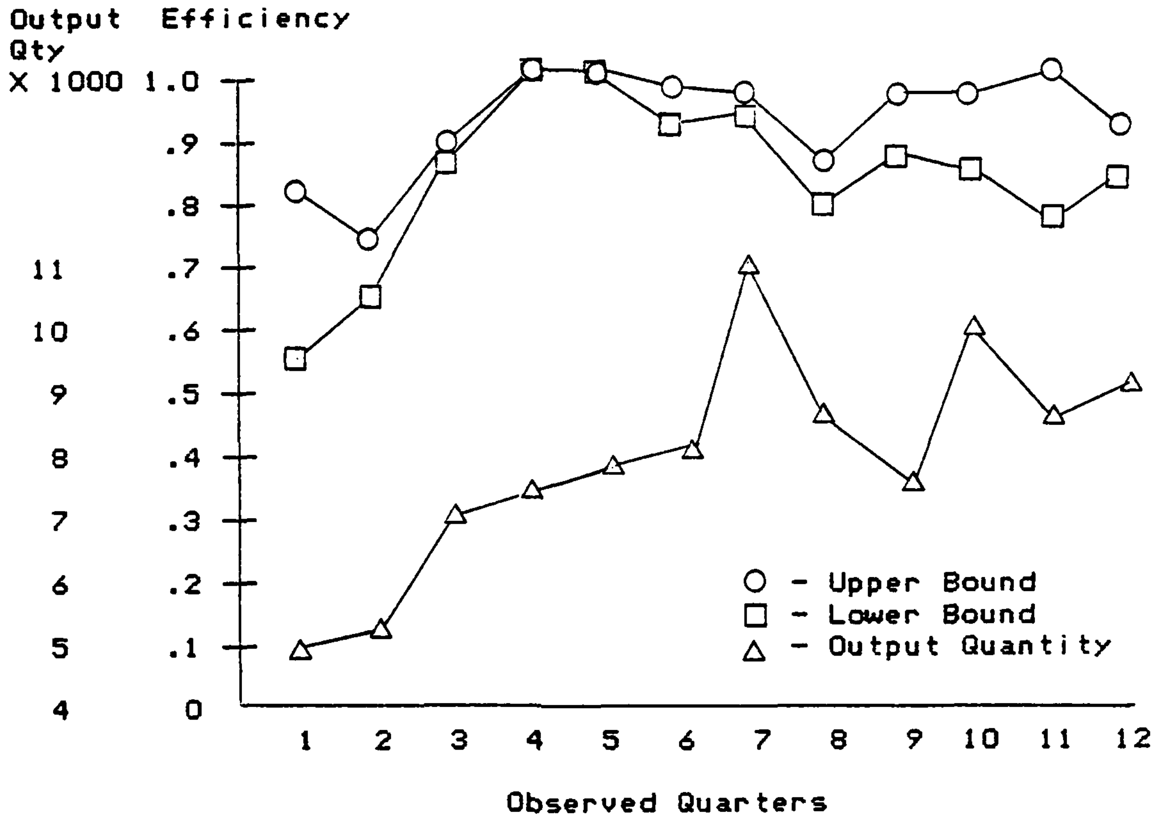


Observed Quarter	Lower Bound	Upper Bound	Output Quantity
1981			
1	.566	.822	4967.7
2	.645	.751	5335.8
3	.888	.891	7024.4
4	1.000	1.000	7283.8
1982			
5	.919	.920	7840.8
6	.827	.982	8028.7
7	.912	.947	10823.5
8	.804	.852	8416.0
1983			
9	.912	.932	7581.1
10	1.000	1.000	9742.7
11	.871	.947	8165.0
12	.985	.987	8837.2

Figure 7. Test 4, One Output, Inputs Adjusted for Inflation with No Labor Hours.

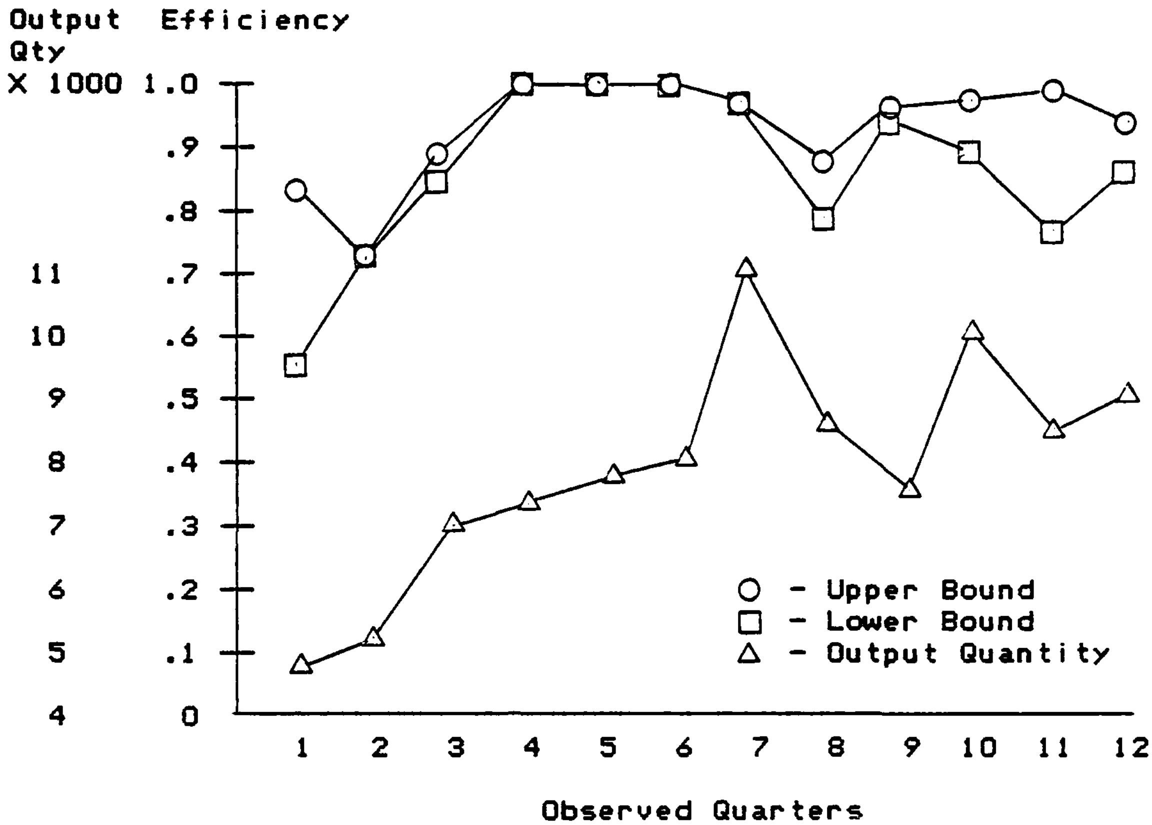
Tests 5 and 6 Analysis. Tests 5 and 6 evaluated one output and three inputs that excluded labor dollars and included labor hours. Test 5 was not adjusted for inflation while Test 6 included an adjustment. The general relationships of the observed quarters were similar to the previous models, but differences were identified. Observed quarter 5 returned to the frontier as in Tests 1 and 2 and remained there with the inflation adjustment in Test 6. Observed quarter 6 was rated efficient and added to the frontier in Test 6. However, observed quarter 10 was not rated efficient in either Test 5 or 6, as it was in the first four tests. Also, the average yearly upper bounds of efficiency did not increase from 1982 to 1983.

These results support the suggestion in the previous section that labor hours and labor dollars are allocated to the hydraulic shop independently. Depending on which measure of labor is used, some observed quarters are rated differently and the frontier changes significantly.



Observed Quarter	Lower Bound	Upper Bound	Output Quantity
1981			
1	.566	.822	4967.7
2	.655	.733	5335.8
3	.877	.891	7024.4
4	1.000	1.000	7283.8
1982			
5	1.000	1.000	7840.8
6	.909	.981	8028.7
7	.950	.981	10823.5
8	.784	.862	8416.0
1983			
9	.874	.944	7581.1
10	.852	.951	9742.7
11	.756	.983	8165.0
12	.822	.893	8837.2

Figure 8. Test 5, One Output, Inputs Not Adjusted for Inflation with No Labor Dollars



Observed Quarter	Lower Bound	Upper Bound	Output Quantity
1981			
1	.566	.822	4967.7
2	.721	.724	5335.8
3	.866	.879	7024.4
4	1.000	1.000	7283.8
1982			
5	1.000	1.000	7840.8
6	1.000	1.000	8028.7
7	.985	.986	10823.5
8	.780	.870	8416.0
1983			
9	.916	.944	7581.1
10	.892	.952	9742.7
11	.783	.983	8165.0
12	.862	.920	8837.2

Figure 9. Test 6, One Output, Inputs Adjusted for Inflation with No Labor Dollars

The single output model tests, although different in some respects, do show similarities. The first two observed quarters received the lowest efficiency ratings in all six tests. Also in Tests 1 through 4, the average yearly upper bound efficiency rating increased each year from 1981 through 1983. This suggests an increase in productivity as measured by technical efficiency. However, when the tests were forced to evaluate efficiency using labor hours and not labor dollars in Test 5 and 6, efficiency did not improve from 1982 to 1983 as in the previous tests.

Part II. Partial Output Model

Tests 7 and 8 Analysis. Tests 7 and 8 were designed to evaluate all input expenditures to the output quantities of the 26 most repaired items listed in Table VI below.

TABLE VI

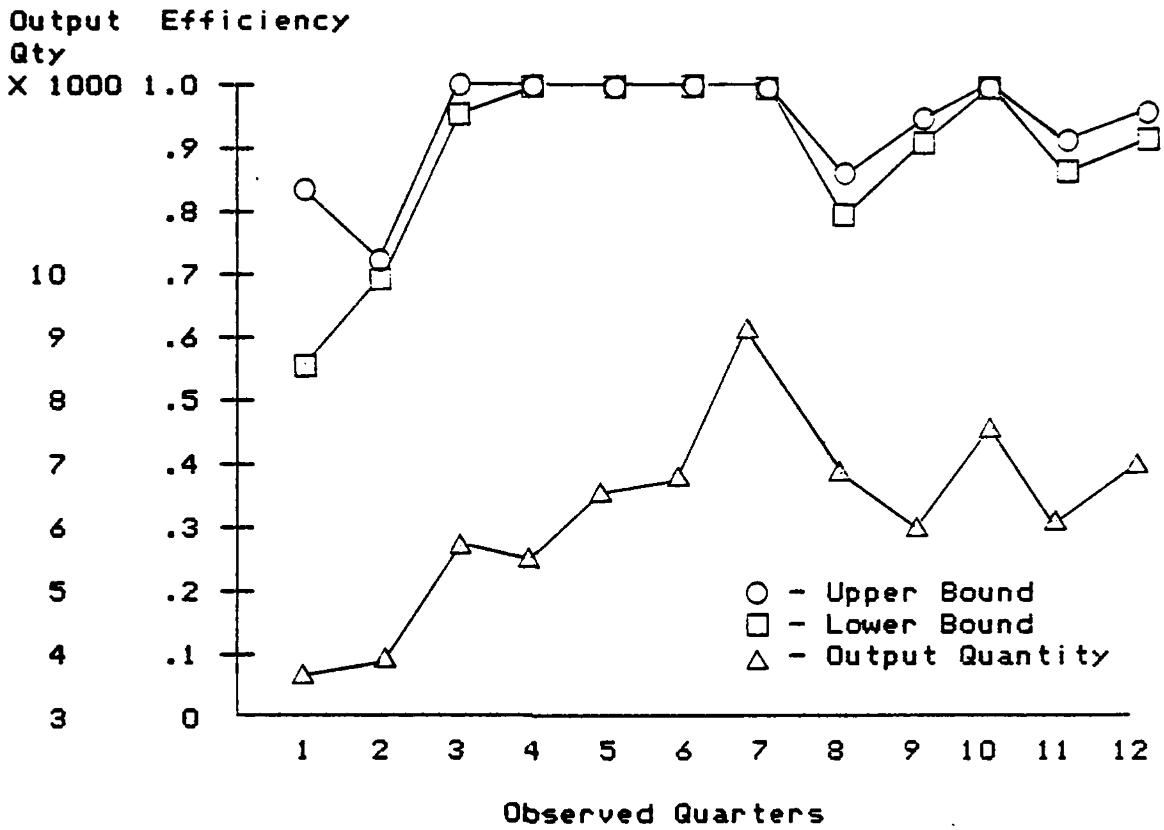
Output Quantities for Tests 7 and 8

Observed Quarter	Output Quantity	Observed Quarter	Output Quantity
1981			
1	3689.4	7	9085.8
2	3936.7	8	6647.5
3	5736.5	1983	
4	5405.6	9	5940.2
1982		10	7481.1
5	6411.8	11	5955.1
6	6641.6	12	6679.7

Test 7 was employed without inputs adjusted for inflation, while Test 8 included the inflation adjustment. The purpose was to develop estimates of efficiency by considering items most frequently repaired.

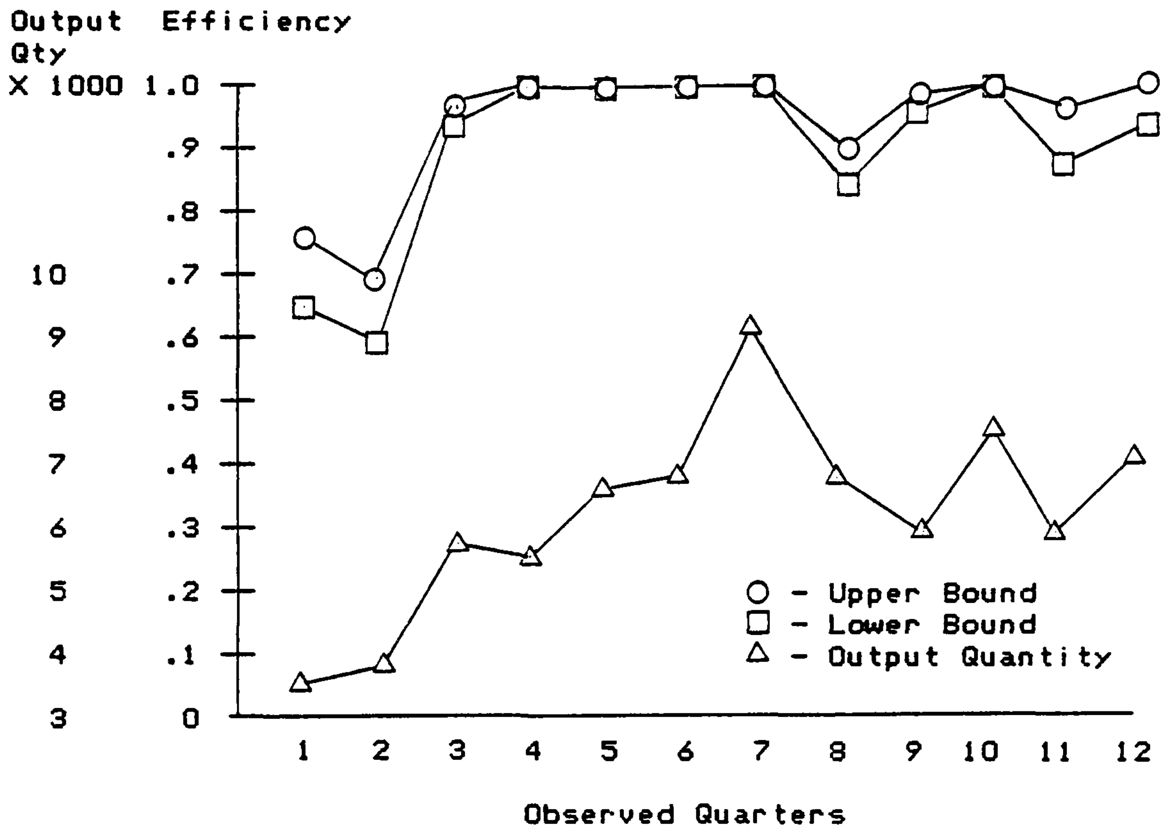
The results of these two tests suggest that this concept produces meaningful results but at some sacrifice of accuracy. The ratings assigned by this model compares closely with the results of Tests 1 and 2, the tests considered most comprehensive and accurate by the authors. If estimates in efficiency ratings are all that are needed for management decisions, then substantial efforts to collect data may be saved.

The reader should note that the output quantity scales in Figures 10 and 11 have changed. The graph begins at 3000 and ends at 10,000 because observed output quantities are less than in Tests 1 through 6.



Observed Quarter	Lower Bound	Upper Bound	Output Quantity
1981			
1	.567	.823	3689.4
2	.683	.711	3936.7
3	.947	.993	5736.5
4	1.000	1.000	5405.6
1982			
5	1.000	1.000	6411.8
6	1.000	1.000	6641.6
7	1.000	1.000	9085.8
8	.785	.867	6647.5
1983			
9	.920	.942	5940.2
10	1.000	1.000	7481.1
11	.860	.905	5955.1
12	.927	.938	6679.7

Figure 10. Test 7, One Output (Top 26), Inputs Not Adjusted for Inflation



Observed Quarter	Lower Bound	Upper Bound	Output Quantity
1981			
1	.648	.752	3689.4
2	.600	.695	3936.7
3	.940	.961	5736.5
4	1.000	1.000	5405.6
1982			
5	1.000	1.000	6411.8
6	1.000	1.000	6641.6
7	1.000	1.000	9085.8
8	.832	.883	6647.5
1983			
9	.932	.950	5940.2
10	1.000	1.000	7481.1
11	.847	.938	5955.1
12	.945	.971	6679.7

Figure 11. Test 8, One Output (Top 26), Inputs Adjusted for Inflation

Part III. Multiple Output Model

Tests 9 and 10 Analysis. These two tests were employed to evaluate three outputs and four inputs. Test 9 was not adjusted for inflation, while Test 10 include an adjustment. Table VII shows the values of the Outputs 1, 2 and 3. Outputs 1 and 2 were two items repaired by the hydraulic shop with the highest individual output quantities over the test period. Output 3 represents a combined output quantity of all other items in the hydraulic shop. It was hoped an individual analysis of Outputs 1 and 2 would reveal additional information useful to management. The graphs in Figures 12 and 13 do not show the output quantity since multiple outputs cannot be displayed.

TABLE VII

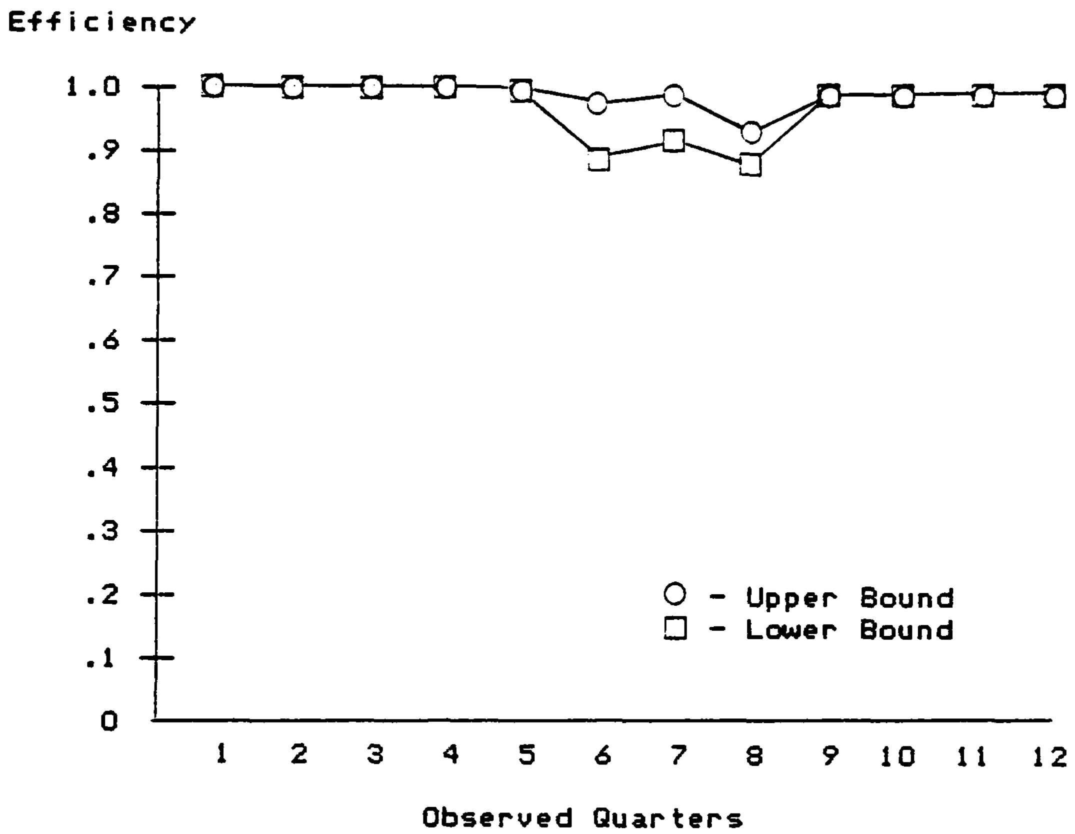
Three Output Quantities for Tests 9 and 10

Observed Quarter	Output 1	Output 2	Output 3
1981			
1	43.5	365.7	4558.5
2	377.0	402.8	4556.0
3	745.0	413.4	5857.0
4	594.5	339.2	6350.0
1982			
5	493.0	312.7	7035.1
6	609.0	323.3	7096.4
7	609.0	434.6	9779.9
8	797.5	339.2	7279.3
1983			
9	681.5	439.9	6459.7
10	739.5	731.4	8271.8
11	768.5	159.0	7237.5
12	551.0	238.5	8047.7

This model produced little information considered useful to management. The results of Test 9 showed only three observed quarters (6, 7 and 8) as less than efficient. In Test 10 with the inflation adjustment, the number of inefficient observed quarters was reduced to two, quarters 2 and 8. This information does not support the results of the single and partial output models that consistently rated observed quarters 1, 2, 3, 8, 9 and 12 inefficient.

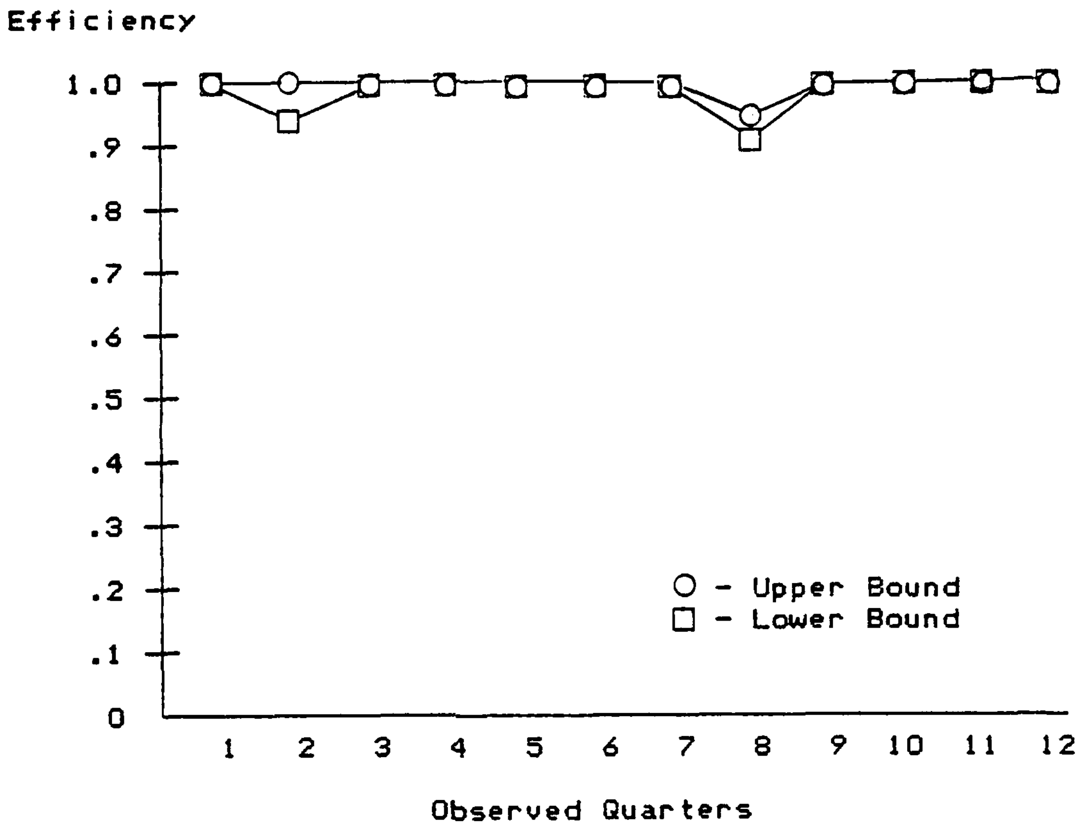
These results show a limitation of the DEA and CFA techniques when used for small data sets. As in Tests 3 through 6, the benevolence of the DEA and CFA models is a factor. By dividing the total output quantity into two small quantities and one large quantity, the model was given considerable freedom to ignore inefficient parts of the output data. The model's efforts to assign the highest possible efficiency rating degrades the diagnostic value of the results by regarding all but a few observed quarters as efficient. The model designer should consider the diagnostic limitations of a model with too few observations.

Although the multiple output formulation was not the best configuration for this small data set, its usefulness should not be disregarded. If a large set of observations had been used so that the hydraulic shop could be modeled with each production item as a separate output, then a multiple output results may have been valuable.



Observed Quarter	Lower Bound	Upper Bound
1981		
1	1.000	1.000
2	1.000	1.000
3	1.000	1.000
4	1.000	1.000
1982		
5	1.000	1.000
6	.897	.988
7	.933	.993
8	.910	.935
1983		
9	1.000	1.000
10	1.000	1.000
11	1.000	1.000
12	1.000	1.000

Figure 12. Test 9, Three Outputs, Inputs Not Adjusted for Inflation



Observed Quarter	Lower Bound	Upper Bound
1981		
1	1.000	1.000
2	.954	.997
3	1.000	1.000
4	1.000	1.000
1982		
5	1.000	1.000
6	1.000	1.000
7	1.000	1.000
8	.896	.938
1983		
9	1.000	1.000
10	1.000	1.000
11	1.000	1.000
12	1.000	1.000

Figure 13. Test 10, Three Outputs, Inputs Adjusted for Inflation

Summary

The single output model (Tests 1 through 6) demonstrated the sensitivity of the DEA and CFA analysis techniques to the data characteristics of this study. Changes such as the inflation adjustment produced consistent results over several formulations. The differing results of Tests 3 and 4 and Tests 5 and 6 demonstrated the importance of the input/output selection process. The first six tests taken together also show DEA/CFA modeling flexibility that allows the model designer to tailor the analysis to specific user needs.

The results of the partial output model (Tests 7 and 8) show the feasibility of using DEA/CFA analyses with only part of the output that is considered significant. On the other hand, the multiple output model (Tests 9 and 10) results showed that there are limitations to using partial output in the analysis. Providing a DEA/CFA model too much freedom degrades the usefulness of the results showing attention must be paid to the size of the data base and the nature of the outputs.

In Chapter V, the validation of this chapter will be reported. In Chapter VI, the authors will draw conclusions about the research effort and recommend further research and applications of the DEA and CFA analysis techniques.

V. Validation

The final step in the research effort is a two-stage validation process. The first stage is a verification of the accuracy of the DEA and CFA mathematical calculations by performing identical tests on the University of Texas (UT) CDC CYBER computer, using the originally developed DEA and CFA softwares. The second stage is an interpretation of the modeling results by using managers. Interpretation of results by using managers would suggest that DEA and CFA productivity measurement techniques in the AFLC maintenance environment are useful and, more importantly, acceptable to managers.

University of Texas (UT)

The mathematical results of the ten tests reported in the previous chapter were similar to the UT CYBER results. However, there were some differences and some insights discovered in the results.

Differences. A slight difference in large numbers was attributed to numerical rounding differences between the two computers. However, the rounding differences did not affect any significant digits in the results.

Also, a difference in computer software features did affect the assignment of lower bounds of efficiency for some observed quarters. This occurred because of different

stopping rules in Fraser's versus UT's software. As optimization models, DEA and CFA must have a predetermined stopping point where the next iteration of results is not considered any better because of some property associated with the calculations. Fraser's softwares directed the CFA model to calculate the lowest efficiency rating possible for a given inefficient DMU relative to the frontier set of efficient observed quarters. The UT softwares used the same CFA procedure but calculated the maximum of the lower bounds relative to the frontier set of efficient observed quarters.

According to CLark (9), either method of establishing a lower bound can be considered valid. The most appropriate stopping rule should be determined by examining the planned uses for the results. Fraser's stopping rule for displaying the lower bound was considered more useful for this research because managers could use the information for worst case planning.

Insights. The effect of differing correlation relationships among inputs and among outputs on the efficiency rating was examined at UT. Dr. Athella Bessent, associate professor at UT and a CFA co-developer (2), suggested that an input should have a negative rate of substitution with another input and likewise for outputs. Current research at UT suggests that by selecting inputs with negative rates of substitution an optimization model such as DEA or CFA is able to consider a mix of those two inputs versus selecting one input or the other to compute

efficiency ratings. However, if two inputs are selected which have a highly positive correlation, the efficiency ratings would be essentially the same if one or the other or both variables were included in the analysis.

For this research, input to input and output to output correlations were calculated to screen inputs and outputs for rates of substitution. These correlations showed positive rates of substitution among the inputs and negative rates among the outputs in the multiple-output model. Therefore, additional tests of the multiple-output model were devised using one input at a time compared to the three outputs. The results showed better formed frontiers with the one input, multiple-output formulation. The implications were that inputs and outputs with negative rates of substitution relationships should be selected. These results are not conclusive and were only intended to add to the current body of UT research. Future DEA/CFA research should check with UT for progress in this area.

Sacramento Air Logistics Center (SMALC)

The importance of incorporating management as well as modeling expertise in model design cannot be overstated. The close cooperation between the users and model designers is essential for meaningful and valid results. The following presents observations of a tour in the hydraulic shop and the authors' personal interviews with managers that were familiar with this shop.

Hydraulic Shop. The hydraulic shop was originally chosen by AFLC managers for this research because of its degree of stability and autonomy as a process. However, direct observation of the work environment showed several batch process situations and considerable "farming out" of work. Although disassembly and reassembly of components were accomplished in the hydraulic shop, other processes, such as performance testing or welding, were usually performed elsewhere.

The DEA and CFA modeling reflects the effects of these subprocess efficiencies on the efficiency of the shop as a whole. However, different choices in the input/output selection process may have improved the efficiency diagnosis of the results. There were numerous instances of interactive effects among subprocesses. For example, if direct and indirect costs had not been combined, natural trade-offs, such as labor versus machine intensive operations, may have been easier to identify. The impact on shop efficiency of these subprocesses should be considered

when determining the efficiency of shops in future research.

Personal Interviews. At SMALC, the results were presented to James Wallen, Deputy Chief of the Resources Management Division, members of his staff, and George Klinas, Supervisor of the Pneudraulic Motor and Miscellaneous Unit Resource Control Center (the hydraulic shop) (24). Additional conversations were held with Ron Orr, Chief of the Industrial Products Division, and others within the Directorate of Maintenance (24). In each case, these managers considered the inputs and outputs and the results of the modeling effort as accurate and useful information for management decision making. Although detailed historical documentation of the hydraulic shop was not available for comparison, observations made and opinions expressed by Mr. Klinas and others were considered support for the validity of the modeling results.

Mr. Wallen was fascinated by the possibilities of DEA and CFA and expressed interest in an expanded study. He wished to continue the hydraulic shop research, doing an analysis that included tracking the effects on efficiency of a planned shop reorganization and move to a new facility. Also, he wished to see the techniques applied to other shops with different types of resources and production flows. Mr. Orr concurred with Mr. Wallen and wished to see DEA and CFA analyses applied to shops in the Industrial Products Division.

Although upper and middle management acceptance of DEA/CFA modeling is encouraging, acceptance by first line management is equally important. Discussions with the hydraulic shop supervisor, Mr. Klinas, provided several insights to questions raised in Chapter IV. Mr. Klinas believed that the sharp increase in output quantity in observed quarter 7 was probably caused by the hydraulic shop assuming additional responsibilities. In observed quarter 7, the hydraulic shop was merged with another shop and simultaneously a dramatic increase occurred in the overhaul of some F-15 tactical fighter hydraulic components. The DEA/CFA results indicate a successful merger and smooth production increase since there was a 98 percent efficiency rating for the observed quarter (reported in Test 1 and 2 of Chapter IV). Additionally, Mr. Klinas was reasonably sure that the drop in efficiency in observed quarter 8 could be attributed to a residual temporary work force and some lags in the accounting process from the previous quarter.

Summary

The results of measuring the technical efficiency of the hydraulic shop were enthusiastically accepted by the SMALC managers. In addition, management planned to incorporate DEA/CFA into their computer facilities and continue analysis of the hydraulic shop while undertaking an analysis of other shops.

The validation process is valuable to understanding the usefulness and implications of the research findings. It confirmed that the IBM PC computer softwares were logically correct and the results were computed correctly. Knowing the effects of optimization stopping rules, rates of substitution among variables and the effects of subprocesses are necessary considerations for future DEA/CFA modeling efforts.

In retrospect, many of the observations made and lessons learned after-the-fact in the validation stage would have enhanced the modeling effort considerably if the information had been available earlier. However, the purpose of this research, to evaluate the feasibility of using the DEA/CFA techniques in a ALC maintenance environment, was successfully accomplished and accepted by SMALC and HQ AFLC managers as a valid way of measuring productivity in their organization.

VI. Conclusions and Recommendations

The following presents the conclusions and recommendations of this thesis. The conclusion restates the research problem and then summarizes the results of each objective from Chapter I. The recommendations are presented by the authors for future research efforts.

Conclusions

Chapter I presented the thesis problem and a list of the five research objectives. The problem stated was that Air Force Logistics Command has been unsuccessful in measuring productivity since past measurement techniques were insufficient. This was stated in an HQ AFLC thesis proposal (16) and confirmed in interviews with managers at HQ AFLC (22) and SMALC (14).

Objective One. The first objective, (1) to define productivity for AFLC depot-level maintenance, is met with the literature review in Chapter II. Productivity is traditionally defined as some function of effectiveness and efficiency. For purposes of this research, effectiveness is combining all inputs into useful outputs, whereas, efficiency is the conservation of input resources while producing a maximum number of outputs. This research measured technical efficiency by applying DEA/CFA techniques while assuming outputs meet the effectiveness criteria of

the organization.

Objectives Two and Three. The third chapter accomplishes objectives two and three, which are: (2) to establish criteria and select input and output measurements, and (3) to develop the relationship between selected inputs and outputs using DEA and CFA. DEA and CFA analyses was explained and illustrated in detail to show that DEA and CFA efficiency ratings are relative and based on the empirical data. The process of selecting inputs and outputs was accomplished with the help of Dwyer (14), illustrating the need for close cooperation between managers and modelers early in the modeling process. The relationships between selected inputs and outputs were formulated into three models representing ten tests. The rationale for each test was discussed along with some of the expected results.

Objective Four. The groundwork for objective four, (4) evaluating the DEA and CFA models using AFLC data, begins in Chapter IV and is validated in Chapter V. The single-output model (Tests 1 through 6) showed the flexibility available with DEA/CFA's models to tailor the analyses to specific user needs. Tests 1 and 2 were considered the most accurate since they evaluated all the selected inputs and outputs simultaneously. The results of the partial output model (Tests 7 and 8) show useful results can be obtained when only significant portions of the output quantities are considered. This model could be considered useful when data collection is expensive (in terms of time and money) and

good estimates of efficiency can support management decision making. Lastly, the multiple output model (Tests 9 and 10) produced little information useful to management. The results show a limitation of using DEA and CFA techniques for small data sets because the model had too much freedom to ignore portions of the data.

Interviews with managers establishes that DEA and CFA techniques were improvements over past measurement efforts and could reliably report technical efficiency in the maintenance environment. The managers believed that the results were valid and could produce information directly beneficial to their decision making. They enthusiastically suggested further DEA/CFA research and planned to investigate these techniques with other shop applications.

Summary. The authors believe that productivity measurement in depot-level maintenance environments is a valid problem because past measurement techniques were insufficient. DEA and CFA techniques are improvements over past measurement efforts and, if used properly, should meet the information needs of maintenance managers at any level. They are useful measurement techniques for AFLC depot-level maintenance because they can produce information that is directly beneficial to managerial decision making. A DEA/CFA model could be developed to reliably report technical efficiency in any maintenance environment given that close cooperation between the users and model designers is established. Lastly, these authors suggest that

effectiveness as well as efficiency could be measured given proper input/output selection and an expanded data base.

Recommendations

Objective five, (5) suggestions for further research and suggested Air Force DEA and CFA applications, is met in this section with the following recommendations:

1. HQ AFLC should participate in the input and output selection process research with the University of Texas. Current studies at the UT Educational Productivity Council suggest that the relationships of the variables affect the quality of the analysis. Statistical studies, such as correlations and preliminary CFA results, should be examined for use in the input and output selection process.

2. HQ AFLC needs to explore additional applications of DEA and CFA in the maintenance environment by continuing the hydraulic shop analysis and analyzing other shops in SMALC and other Air Logistic Centers. Also, DEA/CFA application research and test at Newark Air Logistics Center would seem to be ideal because of Newark's small output size, stability, actual accounting system and degree of automation. HQ AFLC managers are anxious to dedicate in-house resources if any of the above research recommendations are undertaken.

3. A productivity research center should be established at AFIT to serve as a focal point for the Air Force productivity research efforts much like the Educational Productivity Council at the University of Texas serves as a focal point for productivity improvement efforts of over 600 secondary schools. AFIT should be the focal point for Air Force productivity research because this type of research is consistent with AFIT research objectives and the faculty includes the co-inventor of CFA and other members who are currently researching the potential uses of DEA and CFA analyses.

4. The Department of Defense needs to study other DOD applications of DEA/CFA analyses. The flexibility of the DEA/CFA techniques suggests endless possibilities for applications in administration, aircraft and ballistic missile operations, transportation and distribution fields and logistics planning.

An unprecedented opportunity exists between HQ AFLC managers, AFIT students and faculty advisors and the University of Texas researchers to work together on the important problem of productivity measurement in the Air Force. HQ AFLC needs to implement a productivity analysis system that is academically valid, useful to all levels of management and supportive of the command's information needs. AFIT should take advantage of this opportunity to

mesh graduate student research with real world problems in AFLC. Considerable research is still needed, not just with DEA and CFA applications but also with other AFLC productivity analysis needs.

Appendix A: Glossary of Terms

All Other Dollars - An input variable for DEA and CFA analyses derived by subtracting total labor dollars and total material dollars from total cost dollars extracted from the Form G035A (Appendix B).

Constrained Facet Analysis (CFA) - An extension of Data Envelopment Analysis which analyzes efficiencies for DMUs that are not fully enveloped and provides upper and lower bound measures of efficiency. The actual efficiency measure is somewhere between the upper and lower bound.

Constraint - An equality or inequality that restricts or limits the linear fractional programming objective function to certain feasible solutions.

Data Envelopment Analysis (DEA) - A linear fractional program that evaluates multiple inputs and outputs simultaneously through multi-dimensional mathematics forming a frontier of efficiency and providing a relative efficiency rating for each decision making unit.

Decision Making Unit (DMU) - An organizational element that is being analyzed such as a warehouse or shop.

Effective - Producing outputs quantities with input resources that are of sufficient quality and consistent with the quantity and timeliness goals of a person or an organization.

Efficient - Producing more outputs with the same input resources or producing the same outputs with less input resources.

Efficiency - The ratio of outputs produced or work completed divided by input resources consumed.

Envelopment - A characteristic of DEA analysis where the efficiency measure of an inefficient decision making unit is determined from comparison with a complete frontier facet which is defined entirely by empirical observations so that the upper and lower bounds of efficiency are equal.

Harddisk - the physical equipment to store programs and procedures to aid the computer operation.

Inflation Factors - Inflation percentages from the Office of the Secretary of Defense for Proposed Budget and Sales that were used to adjust 1982 and 1983 input variables (expressed as dollars) to 1981 dollars.

Labor Hours - Actual man hours worked that were extracted from Form G035A (Appendix B) and used as an input variable for the DEA/CFA analysis.

Linear Fractional Program - A specific type of nonlinear program that evaluates a ratio of linear expressions.

Linear Program - A mathematical problem which has an objective function and constraints where all mathematical expressions are linear.

Lower Bound Efficiency - The lowest possible efficiency rating for a given decision making unit.

Model - A mathematical representation of a real situation.

Not-For-Profit Organization - An organization whose goal is not to make a profit but to provide a service such as a hospital or the Department of Defense.

Objective Function - A mathematical expression that is either maximized or minimized and is limited by its set of constraints.

Observed Quarter - Three months of a fiscal year in which all inputs and outputs are summed and used as variables for the DEA/CFA models.

Output Quantity - The result of multiplying shop direct activity hours times the number of items repaired that were extracted from Form G019C (Appendix B) and compiled as output data (Appendix C) for DEA and CFA analyses.

Partial Ratio - One output amount divided by one input amount when multiple inputs and multiple outputs are present.

Piece-Wise-Linear Frontier - A frontier formed by the most efficient decision making units where each facet of the frontier is a linear combination of efficient observations.

Production Function - A function that provides the theoretical maximum amount of output obtained from the given level of inputs of a process.

Productivity - A function of effectiveness and efficiency, the ratio of outputs produced divided by the inputs consumed where outputs are useful and consistent with the goals of a person or organization.

Quality - A standard by which an item or value is judged.

Ratio - The quotient of one number divided by another.

Software - Programs used to simplify the use of a computer operating system.

Technical Efficiency - A measure of a firms success in achieving the maximum output from inputs expended expressed as a ratio of an observed level of outputs over inputs divided by a maximum value of outputs over inputs on the piece-wise linear frontier.

Timeliness - A state of being early or on time.

Total Factor Ratio - A ratio of all outputs over all inputs in an organization.

Total Labor Dollars - The sum of direct labor dollars plus indirect labor dollars extracted from Form G035A (Appendix B) and used as an input variable for the DEA and CFA analyses.

Total Material Dollars - The sum of direct material dollars plus indirect material dollars extracted from Form G035A (Appendix B) and used as an input variable for the DEA and CFA analyses.

Upper Bound Efficiency - The highest possible efficiency rating for a given decision making unit.

Appendix B: Sample Data Source

Input Data Source (Form G035A)

HQS

[illegible] OPERATING COST REPORT SMALL MONTHLY G035A-H[illegible]3-C1 31 OCT 1980 PERFORMING

	FUNDED BUDGET	ACC ACTUAL	TOTAL ESTIMATED INCOME	BUD RATE	MONTHLY ACT RATE	BUD-ACT COST VAR	EST-ACT COST VAR	BUD-ACT YTD COST VAR	EST-ACT YTD COST VAR
ACTIVITY HR	2,233.0	[illegible]							
DIR LABOR	[illegible]	[illegible]	36,[illegible]	12,562	14,202	13,107.30	6,485.74	13,107.30	6,485.74
DIR LAB OTH	.00	.00	.00	.000	.000	.00	.00	.00	.00
DIR EXP MAT	125,141.54	[illegible]	163,317.56	56.067	52.665	28,265.53	9,910.49-	28,265.53	9,910.49-
OTH DIR CST	.00	.00	.00	.000	.000	.00	.00	.00	.00
RAC SHP CST	.00	.00	.00	.000	.000		4 CODED HOURS EQUAL		822.9
SHOP (OPER OVERHEAD)									
IND LAB	4,857.99	5,579.21	6,353.02	2.181	[illegible]	711.22	774.02-	711.02	774.02-
IND MAT	3,193.99	3,380.66	4,168.36	1.431	1.161	186.67	787.70-	186.67	787.70-
IND OTH	.00	.00	.00	.000	.000	.00	.00	.00	.00
TOT SHP O/H	8,061.98	8,959.67	10,521.39	3.612	3.076	897.69	1,561.72-	897.69	1,561.72-
SHOP SUPP									
SECT DIR	377.21	553.39	492.28	.169	.190	176.18	61.11	176.18	61.11
ENG PLAN	[illegible]	4,[illegible]	[illegible]	[illegible]	1.320	883.97	81.54-	883.97	81.54-
SCHED	3,835.65	5,173.93	4,992.71	1.716	1.776	1,348.28	181.22	1,348.28	181.22
QUALITY	2,292.26	2,449.49	2,991.55	1.027	.841	157.23	542.06-	157.23	542.06-
[illegible]	2,167.27	[illegible]	2,828.43	[illegible]	.603	409.84-	1,271.00-	409.84-	1,271.00-
TOT SHS	[illegible]	13,983.19	15,435.46	5.299	[illegible]	2,155.82	1,452.27-	2,155.82	1,452.27-
[illegible]	[illegible]	[illegible]	14,552.85	[illegible]	[illegible]	1,288.66-	4,690.44-	1,288.66-	4,690.44-
TOTAL COST	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13,129.18-	[illegible]	13,129.18-
G072A ACC [illegible]		.00			.000				
G072A ACC OPER OTH		.00							
EXPECTED GAIN-LOSS		13,129.18	5 %						
RAC SHP ACC		.00			.000				

Output Data Source (Form G019C)

30 SEP 83 — SOR MISTR MASTER (AVSN) C16 — A - GO19C-CAK-CA-MCU

PERIOD 01 FISCAL YEAR 83 — SOR SM — PAGE 199

ACTUAL NSN / MASTER NSN / CNTRL NUMBER D	MMC / MMC / FLOW DAYS	WEAPON SYS APPLICATION / PSEUDO CODE	IND SPEC	MCLN ERRC / SM ALC	MISC CODE / MGR DES	END ITEM UNIT COST / ORGAN S CODE D	E-I SDPH / ORGAN SDPH	MIEC SMC	QWO / COND PERC	1ST QTR	2ND QTR	3RD QTR	4TH QTR	TO-DATE
632000162060BHS		A70		PUMP,HYD		2368.00	7.3	06	18	9	22	27	35	93
632000169060BHS				T				P		11	34	32	35	112
										9	22	27	30	98
14512 A	14	SKTH	FOU	OC	NEC	MCPR2 A	5.5		2	14	31	26	31	102
							REPAIR COST			1242.83	1242.83	1242.83	1242.83	
632000180203?AX		AGE GR SPT		PUMP		1569.38	18.6	13	4	20	30	25	28	103
[illegible]				T				P		21	35	29	33	123
										20	30	28	41	116
36816 A	14	EGOX	GPR	SA	GPF	MCPR9 A	18.1		0	24	30	27	41	122
							REPAIR COST			1140.00	1140.00	1140.00	1140.00	
632000[illegible]HS		A70		PUMP,HYD		2271.00	10.6	22	0	5	11	14	12	42
[illegible]				T				P		5	12	9	10	33
[redacted]										5	13	19	15	52
16516 A	6	SKTH	FOU	OC	NEC	MCPR2 B	9.9		6	5	13	15	10	43
							REPAIR COST			1519.80	1519.80	1519.80	1519.80	
632000197512?HS		C-130		PUMP		1246.00	5.2	01	2	1	7	9	8	24
632000152?[illegible]HS				T				P		3	12	11	8	34
										1	7	8	9	25
36182 A	27	SKTH	FOU	OC	NEC	MCPR9 A	5.4		0	3	10	11	9	33
							REPAIR COST			279.96	279.96	279.96	279.96	
632000211509?HS		C130		PUMP		2620.99	6.5	07	5	11	137	120	120	390
632000213[illegible]HS				T				P		10	126	116	133	385
										13	137	120	135	405
22565 A	6	SKTH	FOU	GC	NEA	MCPR9 B	6.5		2	10	133	112	132	387
							REPAIR COST			676.52	676.52	676.52	676.52	
632000[illegible]UH		00000005		PUMP ASSY		603.50	5.8	12	9	3	0	0	3	6
632000237596UH				T				P		0	1	0	3	4
										3	0	0	3	6
20267 A	6	EXTM	GPD	SA	GPE	MCPR2 A	5.8		65	3	1	0	3	7
							REPAIR COST			239.30	239.30	239.30	239.30	
6320[illegible]UH		0005A		MOTOR		1023.00	3.4	28	0	4	0	0	2	6
632000237097UH				T				P		2	0	0	2	4
										4	1	0	2	7
18819 A	5	EXTM	GPB	SA	GPE	MCPR9 A	3.4		65	4	0	0	2	4
							REPAIR COST			127.53	127.53	127.53	127.53	
6320002421797HS		F4E-AFSC		AUXPWR		15962.00	19.3	16	3	8	15	16	0	35
6320002421715HS				T				P		10	16	9	0	35
										8	15	1	8	32
17253 A	9	SKTH	FOU	OC	MVR	MCPR2 A	19.1		2	12	15	1	8	36
							REPAIR COST			1366.09	1366.09	1366.09	1366.09	
6320002421719HS		F4		AUXPWRUT		5593.00	12.1	16	0	0	0	0	0	0
6320002421715HS				T				P		0	0	0	0	0
										0	0	0	0	0
17263 A	9	SKTH	FOU	OC	MVR	MCPR2 A	12.1		2	0		0	0	0
							REPAIR COST			1359.60	1359.60	1359.60	1359.60	

Appendix C: Output Quantity Data

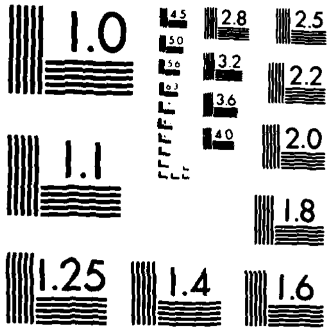
1981 Output Quantities for Each Quarter (Qtr)

Item Number	Qtr 1	Qtr 2	Qtr 3	Qtr 4
15500-00786426BJ,	59.8,	55.2,	119.6,	41.4
16500-00600548BJ,	0.0,	0.0,	11.4,	11.4
16500-00739158 ,	20.8,	31.2,	20.8,	31.2
16500-02041703 ,	78.4,	78.4,	78.4,	78.4
16500-02251878LH,	26.8,	26.8,	26.8,	26.8
16500-02889632 ,	8.8,	8.8,	8.8,	4.4
16500-02889632 ,	.0,	.0,	.0,	.0
16500-11006019 ,	22.5,	126.0,	112.5,	90.0
16500-03515708GK,	.0,	.0,	.0,	.0
16500-03935042BJ,	.0,	.0,	.0,	.0
16500-04040343BJ,	.0,	104.4,	11.6,	232.0
16500-04428061 ,	21.6,	7.2,	28.8,	14.4
16500-04563641LH,	.0,	.0,	.0,	11.6
16500-04770637LH,	5.8,	.0,	.0,	5.8
16500-04866297LH,	83.6,	.0,	296.4,	152.0
16500-04877678LH,	63.7,	9.8,	53.9,	24.5
16500-08159387 ,	79.2,	140.8,	167.2,	149.6
16500-05800482 ,	39.6,	74.8,	22.0,	132.0
16500-07838881MN,	4.4,	.0,	.0,	4.9
16500-05355878 ,	98.0,	98.0,	98.0,	98.0
16500-05400162 ,	39.2,	24.5,	24.5,	58.8
16500-05400172MN,	.0,	.0,	.0,	.0
16500-05400204 ,	9.2,	27.6,	32.2,	23.0
16500-05548102 ,	365.7,	402.8,	413.4,	339.2
16500-05800482 ,	52.8,	70.4,	44.0,	242.0
16500-06911771 ,	.0,	14.8,	.0,	7.4
16500-06846163 ,	.0,	.0,	17.6,	.0
16500-06911771 ,	.0,	.0,	.0,	7.4
16500-07201301 ,	30.8,	26.4,	4.4,	52.8
16500-07282780 ,	112.1,	100.3,	171.1,	241.9
16500-07667961 ,	295.0,	94.4,	112.1,	82.6
16500-07878858 ,	141.6,	194.7,	123.9,	59.0
16500-08159387 ,	96.8,	66.0,	96.8,	136.4
16500-08243321 ,	.0,	.0,	.0,	.0
16500-08252590 ,	176.0,	171.6,	154.0,	176.0
16500-08473742 ,	118.0,	11.8,	.0,	11.8
16500-08889841 ,	55.3,	55.3,	63.2,	.0
16500-08933964 ,	92.0,	103.5,	46.0,	184.0
16500-10091812 ,	.0,	.0,	.0,	.0
16500-09374099 ,	.0,	10.8,	5.4,	.0
16500-09491868 ,	.0,	13.0,	6.5,	6.5
16500-09541429 ,	14.7,	4.9,	.0,	39.2
16500-09930426 ,	60.2,	55.9,	55.9,	55.9
16500-10091812 ,	.0,	15.9,	.0,	.0

AD-A147 329 FEASIBILITY OF MEASURING TECHNICAL PRODUCTIVITY IMPROVEMENTS IN AIR FORE..(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF SYST.. 2/2

UNCLASSIFIED R E HITT ET AL. SEP 84 AFIT/GLM/LSM/84S-30 F/G 13/8 NL

END


1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

Item Number	Qtr 1	Qtr 2	Qtr 3	Qtr 4
16500-10091813 ,	.0,	.0,	.0,	.0
16500-10255260 ,	.0,	.0,	.0,	6.3
16500-10394977BJ,	43.5,	377.0,	754.0,	594.5
16500-10568914WF,	.0,	.0,	.0,	.0
16500-10414568 ,	.0,	.0,	800.0,	800.0
16500-10586259 ,	.0,	.0,	.0,	.0
16800-04083400 ,	13.2,	13.2,	16.5,	6.6
16800-05400164 ,	43.0,	129.0,	124.7,	94.6
41400-04506217BJ,	7.7,	38.5,	23.1,	46.2
43200-00586925HS,	1140.0,	1092.0,	1272.0,	1092.0
43200-01623917HS,	162.0,	121.5,	24.3,	113.4
43200-00620511HS,	.0,	.0,	.0,	.0
43200-01623917HS,	86.0,	68.8,	197.8,	120.4
43200-02135986HS,	32.5,	65.0,	91.0,	91.0
43200-04409598HS,	.0,	13.2,	26.4,	26.4
43200-02898605HS,	.0,	.0,	.0,	.0
43200-02990378HS,	.0,	.0,	.0,	.0
43200-04412858HS,	.0,	.0,	.0,	.0
43200-04515511HS,	.0,	.0,	.0,	.0
43200-04864224HS,	8.8,	13.2,	4.4,	.0
43200-04864224MN,	4.4,	4.4,	.0,	.0
43200-04891667GK,	.0,	.0,	.1,	.0
43200-04891667HS,	258.0,	309.6,	430.0,	430.0
43200-04894688HS,	91.0,	35.0,	28.0,	63.0
43200-04907424LH,	.0,	.0,	2.0,	.0
43200-09235642HS,	.0,	.0,	.0,	.0
43200-05293359HS,	.0,	.0,	14.1,	.0
43200-08055504HS,	.0,	.0,	.0,	23.0
43200-02135986HS,	97.5,	104.0,	104.0,	104.0
43200-05551277HS,	.0,	43.0,	86.0,	64.5
43200-02135986HS,	97.5,	143.0,	169.0,	169.0
43200-06517329HS,	.0,	.0,	.0,	.0
43200-07020269YO,	.0,	.0,	.0,	.0
43200-07059497HS,	.0,	.0,	.0,	.0
43200-07060778HS,	.0,	.0,	.0,	.0
43200-07250479HS,	.0,	.0,	.0,	3.4
43200-07564988HS,	86.0,	47.3,	51.6,	60.2
43200-07608691HS,	40.5,	16.2,	.0,	121.5
43200-07686345HS,	291.5,	323.5,	275.6,	270.3
43200-09334698HS,	18.6,	12.4,	18.6,	.0
43200-02898605HS,	.0,	.0,	.0,	.0
43200-08397642HS,	.0,	.0,	.0,	.0
43200-08648677HS,	.0,	.0,	.0,	.0
43200-08801603HS,	173.6,	140.0,	84.0,	151.2
43200-09235642HS,	.0,	.0,	.0,	.0
43200-02135986HS,	.0,	.0,	.0,	.0
43200-02135986HS,	.0,	.0,	.0,	.0
43200-02135986HS,	.0,	.0,	.0,	.0
61150-11213632UH,	.0,	.0,	.0,	.0

1982 Output Quantities for Each Quarter (Qtr)

Item Number	Qtr 5	Qtr 6	Qtr 7	Qtr 8
15500-00786426BJ,	50.6,	41.4,	92.0,	82.8
16500-00600548BJ,	62.7,	39.9,	17.1,	22.8
16500-00739158 ,	20.8,	.0,	.0,	10.4
16500-02041703 ,	44.1,	39.2,	9.8,	122.5
16500-02251878LH,	26.8,	20.1,	13.4,	33.5
16500-02889632 ,	4.4,	8.8,	13.2,	4.4
16500-02889632 ,	.0,	.0,	.0,	.0
16500-11006019 ,	67.5,	58.5,	4.5,	202.5
16500-03515708GK,	.0,	.0,	.0,	.0
16500-03935042BJ,	.0,	.0,	.0,	.0
16500-04040343BJ,	17.4,	.0,	.0,	81.2
16500-04428061 ,	.0,	36.0,	28.8,	93.6
16500-04563641LH,	5.8,	11.6,	.0,	.0
16500-04770637LH,	11.6,	.0,	.0,	.0
16500-04866297LH,	197.6,	106.4,	83.6,	83.6
16500-04877678LH,	98.0,	.0,	112.7,	9.8
16500-08159387 ,	88.0,	114.4,	132.0,	83.6
16500-05800482 ,	48.4,	44.0,	79.2,	44.0
16500-07838881MN,	4.4,	.0,	8.8,	.0
16500-05355878 ,	196.0,	205.8,	416.5,	367.5
16500-05400162 ,	44.1,	53.9,	63.7,	63.7
16500-05400172MN,	.0,	.0,	.0,	.0
16500-05400204 ,	13.8,	13.8,	.0,	.0
16500-05548102 ,	312.7,	323.3,	434.6,	339.2
16500-05800482 ,	110.0,	114.4,	123.2,	44.0
16500-06911771 ,	.0,	.0,	.0,	.0
16500-06846163 ,	.0,	.0,	21.5,	.0
16500-06911771 ,	.0,	.0,	.0,	.0
16500-07201301 ,	74.2,	30.8,	17.6,	44.0
16500-07282780 ,	129.8,	129.8,	35.2,	135.7
16500-07667961 ,	94.4,	106.2,	94.4,	94.4
16500-07878858 ,	106.2,	94.4,	.0,	.0
16500-08159387 ,	52.8,	44.0,	39.6,	39.6
16500-08243321 ,	.0,	.0,	11.6,	.0
16500-08252590 ,	171.6,	220.0,	189.2,	132.0
16500-08473742 ,	5.9,	11.8,	141.6,	35.4
16500-08889841 ,	47.4,	118.5,	79.0,	63.2
16500-08933964 ,	230.0,	138.0,	138.0,	138.0
16500-10091812 ,	.0,	.0,	.0,	.0
16500-09374099 ,	16.2,	48.6,	48.6,	108.0
16500-09491868 ,	.0,	.0,	6.5,	.0
16500-09541429 ,	44.1,	4.9,	29.4,	.0
16500-09930426 ,	34.4,	25.8,	159.1,	159.1
16500-10091812 ,	5.3,	15.9,	26.5,	.0
16500-10091813 ,	6.1,	6.1,	.0,	.0
16500-10255260 ,	.0,	.0,	6.3,	.0

Item number	Qtr 5	Qtr 6	Qtr 7	Qtr 8
16500-10394977BJ,	493.0,	609.0,	609.0,	797.5
16500-10568914WF,	.0,	.0,	.0,	.0
16500-10414568 ,	1200.0,	800.0,	800.0,	.0
16500-10586259 ,	.0,	.0,	40.5,	40.5
16800-04083400 ,	16.5,	19.8,	16.5,	23.1
16800-05400164 ,	156.8,	102.9,	102.9,	245.0
41400-04506217BJ,	15.4,	.0,	.0,	30.8
43200-00586925HS,	.0,	.0,	.0,	.0
43200-01623917HS,	121.5,	170.1,	251.1,	162.0
43200-00620511HS,	1164.0,	970.0,	2240.0,	1067.0
43200-01623917HS,	86.0,	206.4,	103.2,	129.0
43200-02135986HS,	65.0,	65.0,	78.0,	45.5
43200-04409598HS,	8.8,	13.2,	13.2,	35.2
43200-02898605HS,	.0,	.0,	.0,	.0
43200-02990378HS,	.0,	.0,	.0,	.0
43200-04412858HS,	.0,	.0,	.0,	.0
43200-04515511HS,	72.8,	27.3,	54.6,	81.9
43200-04864224HS,	4.4,	.0,	.0,	13.2
43200-04864224MN,	8.8,	4.4,	13.2,	4.4
43200-04891667GK,	.0,	.0,	.0,	.0
43200-04891667HS,	172.0,	292.4,	326.8,	172.0
43200-04894688HS,	140.0,	140.0,	112.0,	56.0
43200-04907424LH,	.0,	.0,	.0,	.0
43200-09235642HS,	.0,	.0,	.0,	.0
43200-05293359HS,	.0,	28.8,	.0,	.0
43200-08055504HS,	.0,	.0,	9.2,	.0
43200-02135986HS,	65.0,	97.5,	162.5,	175.5
43200-05551277HS,	55.9,	73.1,	34.4,	73.1
43200-02135986HS,	188.5,	195.0,	253.5,	136.5
43200-06517329HS,	.0,	.0,	.0,	.0
43200-07020269YO,	.0,	.0,	.0,	.0
43200-07059497HS,	.0,	.0,	.0,	.0
43200-07060778HS,	.0,	.0,	.0,	.0
43200-07250479HS,	.0,	.0,	.0,	.0
43200-07564988HS,	52.8,	61.6,	44.0,	48.4
43200-07608691HS,	.0,	64.8,	243.0,	81.0
43200-07686345HS,	174.9,	227.9,	296.8,	318.0
43200-09334698HS,	.0,	.0,	.0,	.0
43200-02898605HS,	.0,	.0,	.0,	.0
43200-08397642HS,	.0,	.0,	.0,	.0
43200-08648677HS,	.0,	.0,	.0,	.0
43200-08801603HS,	89.6,	140.0,	168.0,	89.6
43200-09235642HS,	.0,	.0,	.0,	.0
43200-02135986HS,	188.5,	195.0,	325.0,	169.0
43200-02135986HS,	422.5,	390.0,	422.5,	390.0
43200-02135986HS,	435.0,	748.2,	626.4,	513.3
61150-11213632UH,	.0,	160.0,	800.0.	880.0

1983 Output Quantities for Each quarter (qtr)

Item Number	Qtr 9	Qtr 10	Qtr 11	Qtr 12
15500-00786426BJ,	27.6,	124.2,	161.0,	138.0
16500-00600548BJ,	.0,	11.4,	28.5,	28.5
16500-00739158 ,	.0,	62.4,	83.2,	40.6
16500-02041703 ,	39.2,	53.9,	58.8,	73.5
16500-02251878LH,	33.5,	40.2,	40.2,	20.1
16500-02889632 ,	13.2,	.0,	17.6,	8.8
16500-02889632 ,	.0,	8.8,	8.8,	8.8
16500-11006019 ,	36.0,	67.5,	54.0,	45.0
16500-03515708GK,	.0,	.0,	.0,	.0
16500-03935042BJ,	.0,	85.8,	14.3,	14.3
16500-04040343BJ,	92.8,	127.6,	220.4,	110.2
16500-04428061 ,	36.0,	57.6,	36.0,	14.4
16500-04563641LH,	5.8,	.0,	.0,	.0
16500-04770637LH,	.0,	5.8,	.0,	.0
16500-04866297LH,	136.8,	144.4,	76.0,	45.6
16500-04877678LH,	137.2,	98.0,	122.5,	151.9
16500-08159387 ,	61.6,	140.8,	74.8,	88.8
16500-05800482 ,	44.0,	48.4,	57.2,	.0
16500-07838881MN,	.0,	26.4,	13.2,	.0
16500-05355878 ,	171.5,	303.8,	328.3,	264.6
16500-05400162 ,	29.4,	29.4,	9.8,	.0
16500-05400172MN,	.0,	.0,	.0,	.0
16500-05400204 ,	.0,	23.0,	9.2,	9.2
16500-05548102 ,	439.9,	731.4,	159.0,	238.5
16500-05800482 ,	52.8,	35.2,	26.2,	.0
16500-06911771 ,	.0,	.0,	.0,	.0
16500-06846163 ,	.0,	.0,	26.4,	30.8
16500-06911771 ,	.0,	.0,	.0,	.0
16500-07201301 ,	22.0,	35.2,	39.6,	44.0
16500-07282780 ,	59.0,	94.4,	35.4,	82.6
16500-07667961 ,	94.4,	94.4,	88.5,	88.5
16500-07878858 ,	.0,	47.2,	59.0,	53.1
16500-08159387 ,	26.4,	79.2,	35.2,	96.8
16500-08243321 ,	.0,	.0,	.0,	5.8
16500-08252590 ,	154.0,	206.8,	162.8,	149.6
16500-08473742 ,	88.5,	29.5,	23.6,	23.6
16500-08889841 ,	118.5,	134.3,	94.8,	158.0
16500-08933964 ,	172.5,	207.0,	23.0,	.0
16500-10091812 ,	.0,	.0,	.0,	.0
16500-09374099 ,	43.2,	37.8,	32.4,	64.8
16500-09491868 ,	6.5,	6.5,	.0,	.0
16500-09541429 ,	.0,	9.8,	19.6,	93.1
16500-09930426 ,	120.4,	137.6,	68.8,	129.0
16500-10091812 ,	90.1,	10.6,	10.6,	10.6
16500-10091813 ,	.0,	.0,	6.1,	.0
16500-10255260 ,	.0,	6.3,	6.3,	.0
16500-10394977BJ,	681.5,	739.5,	768.5,	551.0

Item Number	Qtr 9	Qtr 10	Qtr 11	Qtr 12
16500-10568914WF,	.0,	85.6,	96.3,	53.5
16500-10414568 ,	.0,	.0,	.0,	.0
16500-10586259 ,	40.5,	.0,	81.0,	97.2
16800-04083400 ,	13.2,	.0,	.0,	6.6
16800-05400164 ,	196.0,	176.0,	196.0,	294.0
41400-04506217BJ,	61.6,	38.5,	7.7,	15.4
43200-00586925HS,	.0,	.0,	.0,	.0
43200-01623917HS,	97.2,	16.2,	40.5,	121.5
43200-00620511HS,	1018.5,	717.8,	1018.5,	1164.0
43200-01623917HS,	43.0,	111.8,	163.4,	129.0
43200-02135986HS,	84.5,	890.5,	780.0,	877.5
43200-04409598HS,	.0,	.0,	.0,	.0
43200-02898605HS,	.0,	65.0,	.0,	.0
43200-02990378HS,	144.0,	144.0,	156.0,	156.0
43200-04412858HS,	.0,	.0,	.0,	.0
43200-04515511HS,	9.1,	9.1,	54.6,	91.0
43200-04864224HS,	.0,	8.8,	.0,	.0
43200-04864224MN,	.0,	4.4,	.0,	.0
43200-04891667GK,	.0,	.0,	.0,	.0
43200-04891667HS,	129.0,	60.2,	258.0,	344.0
43200-04894688HS,	35.0,	140.0,	49.0,	70.8
43200-04907424LH,	2.0,	.0,	.0,	.0
43200-09235642HS,	.0,	.0,	.0,	.0
43200-05293359HS,	.0,	.0,	.0,	.0
43200-08055504HS,	.0,	.0,	.0,	.0
43200-02135986HS,	19.5,	6.5,	.0,	.0
43200-05551277HS,	12.9,	73.1,	47.3,	8.6
43200-02135986HS,	201.5,	52.0,	.0,	.0
43200-06517329HS,	.0,	.0,	.0,	.0
43200-07020269YO,	461.5,	475.7,	35.5,	284.0
43200-07059497HS,	65.0,	91.0,	58.5,	97.5
43200-07060778HS,	52.0,	26.0,	6.5,	71.5
43200-07250479HS,	.0,	.0,	.0,	.0
43200-07564988HS,	88.0,	22.0,	66.0,	17.6
43200-07608691HS,	32.4,	81.0,	81.0,	81.0
43200-07686345HS,	291.5,	455.8,	477.0,	530.0
43200-09334698HS,	.0,	.0,	.0,	.0
43200-02898605HS,	.0,	84.5,	45.5,	52.0
43200-08397642HS,	56.0,	19.6,	84.0,	78.4
43200-08648677HS,	15.0,	15.0,	10.0,	10.0
43200-08801603HS,	123.2,	84.0,	106.4,	140.0
43200-09235642HS,	52.0,	45.5,	52.0,	6.5
43200-02135986HS,	266.5,	455.0,	162.5,	357.5
43200-02135986HS,	260.0,	130.0,	.0,	.0
43200-02135986HS,	52.2,	.0.	52.2,	.0
61150-11213632UH,	624.0,	1056.0,	880.0,	800.0

Bibliography

1. Adam, Everett E. Jr. and others. Productivity and Quality. Englewood Cliffs NJ: Prentice-Hall, Inc., 1981.

2. Bessent, Authella M., Assistant Professor of Operations Research. Personal Interviews. University of Texas, Austin, TX, 11-13 June 1984.

3. Bessent, Authella M. and E. Wailand Bessent. "Determining the Comparative Efficiency of Schools through Data Envelopment Analysis," Educational Administration Quarterly, 16: 57-75 (Spring 1980).

4. Bessent, Authella M. and others. "Managerial Efficiency Measurement, Theory and Applications," Unpublished report. University of Texas, Austin TX, 1983.

5. Bessent, Authella M. and others. "Constrained Facet Analysis, A New Method for Evaluating Local Frontiers of Efficiency and Performance," Unpublished report. University of Texas, Austin TX, May 1983.

6. Charnes, A. and others. "Measuring the Efficiency of Decision Making Units," European Journal of Operational Research, 2: 429-444 (November 1978).

7. Charnes, A. and others. "Evaluating Program and Managerial Efficiency: An Application of Data Envelopment Analysis to Program Follow Through," Management Science. 27: 668-697 (June 1981).

8. Clark, Lt Col Charles T. Data Envelopment Analysis and Extensions for Decision Support and Management Planning. PhD dissertation. University of Texas, Austin TX, May 1983.

9. Clark, Lt Col Charles T., Assistant Professor of Logistics Management. Class Lectures. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, February 1984.

10. Cowling, Thomas G. and Rodney E. Stevenson. Productivity Measurement in Regulated Industries. New York: Academic Press, Inc., 1981.

11. Department of the Air Force. Air Force Productivity Enhancement Program (PEP). AFR 25-3. Washington: HQ USAF, 25 February 1982.

12. Department of Defense. DOD Productivity Program. DOD Directive 5010.31. Washington: Government Printing Office, 27 April 1979.

13. Department of Defense. Productivity Enhancement, Measurement, and Evaluation - Operating Guidelines and Reporting Instructions. DOD Instruction 5010.34. Washington: Government Printing Office, 4 August 1975.

14. Dwyer, Roger P., Chief of Financial Management Section, Resources Management Branch, Director of Maintenance. Telephone interviews. Sacramento Air Logistics Center, Sacramento CA, 16 and 25 January 1984.

15. Fraser, Capt John. Graduate Student. Personal Interviews. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, May 1984.

16. Gertge, Joseph E., Maintenance Specialist, Productivity and Evaluation Division, Directorate of Fiscal Management and Productivity, Deputy Chief of Staff for Maintenance. Letter to AFIT/LS, subject: Logistics Management and Facilities Management Thesis Research Topic Proposal. HQ AFLC/MAJE, Wright-Patterson AFB OH, 31 May 1983.

17. Headquarters Air Force Logistics Command. Air Force Productivity Enhancement Program (PEP). AFLC Supplement 1. Wright-Patterson AFB OH, 29 April 1983.

18. Kendrick, John W. and Beatrice N. Vacara. New Developments in Productivity Measurement and Analysis. Chicago: The University of Chicago Press, 1980.

19. Kendrick, John W., Understanding Productivity. Baltimore MD: John Hopkins University Press, 1977.

20. Lloyd, Lt Col Russell F., USAF. Head, Department of Organizational Sciences, School of Systems and Logistics, Air Force Institute of Technology. Personal Interview. Wright-Patterson AFB OH, September 1983.

21. Mali, Paul. Improving Total Productivity. New York: John Wiley & Sons, 1978.

22. Pruett, Barbara. Chief, Productivity and Evaluation Division, Directorate of Fiscal Management and Productivity, Deputy Chief of Staff for Maintenance. Personal Interviews. HQ AFLC/MAJE, Wright-Patterson AFB OH, 5 August 1983, 20 January 1984 and 6 April 1984.

23. Ruch, William A. "Your Key to Planning for Profits," Productivity Brief 6. 1-7 (October 1981).

24. Sacramento Air Logistics Center. Personal Interviews. Sacramento Air Logistics Center, Sacramento CA, 14 June 1984.

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19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

Title: FEASIBILITY OF MEASURING TECHNICAL PRODUCTIVITY IMPROVEMENTS IN AIR FORCE LOGISTICS COMMAND DEPOT-LEVEL MAINTENANCE USING THE DATA ENVELOPMENT ANALYSIS (DEA) AND CONSTRAINED FACET ANALYSIS (CFA) MODELS

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In response to a Headquarters Air Force Logistics Command thesis proposal, this research demonstrated the feasibility of measuring technical productivity in a depot maintenance environment. Linear fractional programming techniques called Data Envelopment Analysis (DEA) and Constrained Facet Analysis (CFA) were used to show that the productivity of not-for-profit maintenance organizations can be reliably measured and directly supportive of management decision making. DEA/CFA analyses can measure multiple inputs and outputs simultaneously and display results in an easily understood format. This research stresses close cooperation between modelers and managers in selecting input/output variables so that information derived from the analysis can be used effectively. The results of this research were accepted by using managers as accurate, simple and useful in their decision making. Additionally, DEA/CFA techniques appear to have a wide range of potential uses in many Air Force organizations where productivity, capacity and resource allocation analysis are needed.